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PRELIMINARY REPORT

ON THE

BUILDING STONES OF NEVADA,

INCLUDING A BRIEF CHAPTER ON

ROAD METAL.

JOHN A. REID.

1904.

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INTRODUCTION.

CHAPTER I.

The statement that the West is undeveloped is undeniably true. It is doubly true of the State of Nevada. Little has been done to develop her natural resources; little is known of the boundless wealth of her mountains and valleys. Yet Nevada is on the eve of a great awakening; with the advent of irrigation thousands of acres of fertile land, now desert like, will be made to yield an abundance of the fruits of the field, and will support a large population. As the community increases in numbers, a demand will arise for all modern improvements, among which two of the most important are, permanent buildings and good roads. It is needless to state that both of these are made possible by the use of stone; stone for erecting substantial, handsome structures, and stone for the betterment of the highways, which are so important to the healthy life of a growing community. It is not needless, however, to state that the principle underlying the choice and use of stone for the above purposes are little understood. Moreover, were these principles understood, little is known of the various rocks in the state available at present. The purpose of this preliminary report, then, is as follows: First, to present the main principles governing the selection and use of building stones and road metal; second, to describe briefly the stones now in use, or that can easily be used, in Nevada, with their location and availability; and third, to attempt to arouse a larger interest in a subject of such vast importance to a healthy commonwealth,

We in the West are prone to build for the day only; tomorrow is allowed to care for itself. This is undoubtedly cheaper at any particular time, but is far dearer in the end. The scale of any civilization may be told from its architecture; the stability of that civilization is shown by the materials used in the architecture. But we are learning to build, not for mere decades, but for centuries of use, and to do this we must use stone. The first cost may be high, but the ultimate expense is low. The result of this is to be seen now in many places. Not only are stone buildings more common, but also the use of stone is seen in bridges, culverts, roads, curbing, and in many other ways too numerous to mention. In a rapidly growing state like Nevada the importance of these considerations cannot easily be overestimated, yet that importance is little realized. The frontier town is one of tents and temporary light wooden buildings. Everything is done with the greatest haste, and calculated to bring in the largest returns for the least expenditure. Every western town has gone through such a period in its growth. After this first newness has worn off a bit, more stable conditions obtain, and almost imperceptably more solid and substantial structures appear, to take the place of the first flimsy ones. In mountainous regions such as Nevada, men have turned instinctively to the rocks in the hills for building materials. As a consequence nearly all of the towns of the state show one or more stone buildings, while in the larger ones, as Reno and Virginia City, brick is common also as a material of construction. Yet even with brick structures, stone is required for cornices, arches, and similar uses. The people need to know something about the proper and improper use of these materials, which of course, is the reason for the writing of this report.

The nature of this subject is more complex than appears on casual inspection. Fundamental principles of three separate sciences all play an essential part; the subject is built upon geology, physics and chemistry. The practical man may believe that he has no time for such considerations, yet the simplest rule of thumb method, if it be right, is founded upon true scientific principles. No man in this advancing age of competition can afford to be ignorant of those things which vitally concern him and his business. Every citizen, directly or indirectly, is concerned with the erection of public buildings, private buildings, and county and city highways. Hampered by lack of facilities for detailed work, a full report on the subject is impossible for some time, yet the time is ripe for a little knowledge to be distributed about these matters.

The chief uses of rock are as follows, in order of their relative importance. First, the largest amount ot stone is used in the construction of buildings, under conditions already mentioned. Second, much of the finest grade of stone is used for monumental and ornamental work. It is not right, nor is it necessary, that nearly all of our rocks for such uses come from outside localities. Third, the importance of crushed rock for the construction of roads is well known. Fourth, in the larger towns and cities, stone curbing is imperative on the graded streets. Fifth, the use of cut stone for bridges and culverts, especially by the railroads, is growing constantly. Sixth, much cut rock is used for sidewalks and by the railroads. Sixth, much cut rock is used for sidewalks and tiling in the most approved buildings. Besides these, there are many lesser uses, such as the construction of piers, break-waters, dams, retaining walls, with such small uses as hitching posts, steps, mounting blocks, and the like. And it is worth noting that this list is constantly increasing.

The text will be divided into five succeeding chapters; a short chapter on the nature of the various rocks, with their classification; a second chapter devoted to the qualities of building stones, good and bad; a third devoted to an account and description of the building stones of Nevada; fourth, a brief chapter on road metal; and lastly a conclusion.

CHAPTER II.

ROCKS: THEIR NATURE AND CLASSIFICATION.

To the average man, any rock is either a granite, a porphyry, a sandstone, or a slate; these terms are all embracing. Were it not that this loose use of terms is productive of actual loss in construction, by causing a misunderstanding of the characteristics of a stone, with consequent misuse, this chapter would be superfluous. But when such a broad error is made as the use of a partially decomposed volcanic rock, an andesite, under the belief that it was a sandstone, which is a rock not often subject to decomposition, at least in the better grades, the writer feels it necessary to present in some detail the various types of rocks found in the earth.

The first question naturally arising is this: What is a rock? A proper definition is as follows: A rock is any material making up an integral part of the earth; that is, any substance which exists in large enough amount to be considered as constituting an essential portion of the globe. This definition, however, though a strictly scientific one, seems rather too broad for our present needs, for by it the soils, water, ice, and all the soft as well as hard materials, are classified under one great head. Here we are only to consider the hard rocks, or stones, and have use for no others. The definition should be kept in mind, nevertheless, for there is no well defined line between a sand and a sandstone, a clay and a shale, or a gravel and a conglomerate.

The rocks of the earth are divided into three grand classes, as follows:

I. The Igneous or Massive Rocks.

II. The Atmospheric, or Stratified Rocks.

III. The Metamorphic, or Changed Rocks.

Let it be understood that in the following remarks under classification, the chief aim has been to present, to the general reader and practical worker, a mere outline showing how rocks are grouped. It is utterly impossible to describe a rock without some knowledge of minerals on the part of the reader, hence the following brief attempts at describing each rock must be understood as incomplete and greatly limited in scope. It is hoped the descriptions may convey some ideas to the practical man as an aid to his work, as well as act as references for the rocks to be later described.

THE IGNEOUS ROCKS.

The Igneous Rocks are those made by the agency of heat, that is, have cooled from a molten condition. They are also called the massive rocks, because of their structure, which is, broadly speaking, the same in all directions. Also the term eruptive is applied to them, because of their origin as eruptive molten masses. These rocks occur in several different ways, as follows:

1. *Batholites,* or those immense masses of igneous rocks, as granites, which form the axes of our greatest mountain ranges. They are characterized by their great size, their evident position beneath other rocks, and the fact that as far as is known they descend to the deep interior mass of the earth.

2. *Laccolites,* or those dome shaped rock masses which have been intruded between layers, or strata, of other rocks, lifting them up like immense blisters. They differ from batholites mainly in the fact that they rest upon other rocks and are smaller in size.

3. *Sheets or Sills,* or those occurrences of igneous rocks which lie between other rocks as mere sheets, or on top of them They differ from laccolites in that they are everywhere of about the same thickness and have caused no doming of superincumbent rocks. They may have been intruded between other rocks, or poured out upon the surface as lava flows, and are usually more nearly horizontal than vertical.

4. *Dykes,* or intrusive masses filling fissures, much as do mineral veins. These dykes usually cut across other rocks, are of great length on the surface compared with their width, and descending to unknown depths. They are usually more nearly vertical than horizontal.

5. *Irregular Masses,* such as volcanic necks, which are merely the hardened lava in the throat or pipe of an extinct volcano, standing up as a more or less conical mass after the wearing away of the soft cone. Also, we have very irregular bodies of igneous rocks of various sizes and shapes which are intruded into overlying rocks. To these, for lack of a better name, the term "stock" is applied. As a grand division, the igneous rocks are those from which all others are derived.

CLASSIFICATION.

To handle this subject of rock classification from a popular standpoint is a delicate task. The principles underlying it can only be partly stated, for obvious reasons. A knowldge of mineralogy cannot be expected, and all that will be done in what follows is to attempt to render intelligible in the simplest possible manner, the main features of the subject. A working knowledge of the simpler minerals, as quartz, feldspar and mica, will be assumed.

The igneous rocks are classified along two lines. First, chemically, they range from acid to basic, with all gradations between. This variation results in the formation of different minerals, so that the chemical rock types have different appearances Secondly, these rocks are classified on a basis of what is called texture. Those which have cooled at great depths from a molten condition have done so slowly, with a result that they are thoroughly crystallized, often coarsely so. On the other hand, those which have cooled on the surface and hence quickly, are glassy, at times being a simple glass. The thoroughly crystalline, deep seated rocks are called *plutonic,* the glassy, surface ones are called *volcanic.* Those which have cooled and solidified a short way below the surface are often spoken of as dyke, trap, or intermediate rocks. In accordance with these two lines of difference, then all rocks which have solidified from a molten condition are classified. It will be noticed that there are, unfortunately, two kinds of intermediate rocks: those chemically intermediate and those occupying a middle position on the basis of crystalline texture. However, when an intermediate rock is mentioned, one of the latter kind will usually be meant, or a dyke rock. The meaning of the various textures may be looked at in this way. A granite, for instance, is the type of an acid plutonic rock. Melted and cooled rapidly it would form a glassy volcanic rock, and, of course, called a rhyolite. Melted and cooled more slowly, yet not so slowly as a deep seated rock looses its heat, an intermediate acid type, with some crystals showing, would result. This rock would be called a quartz-porphyry. A more basic plutonic rock, as a diorite, when similarly treated would yield a volcanic *adesite* and a dyke phase *porphyrite.* These facts are embodied in the following table, in which only the few main types are mentioned. The many varieties and sub-types made by the petrographer are not necessary in such a report as this.

TABLE OF CLASSIFICATION.

COMPOSITION	TEXTURE		
	PLUTONIC	INTERMEDIATE	VOLCANIC
Acid	Granite	Quartz-Porphyry	Rhyolite
Intermediate	Syenite	Porphyry	Trachyte
	Diorite	Porphyrite	Andesite
Basic	Gabbro	Diabase	Basalt
Ultrabasic	Peridotite	LIMBURGITE	

A peculiar fact to be noted about these rocks is this: Of the plutonic rocks the acid ones, the granites, are most common throughout the earth, while of the volcanic rocks the basic, the basalts, are best developed. Another fact is to be noted regarding the different names. For reasons not necessary to state here the names of the intermediate rocks, quartz-porphyry, porphyry and porphyrite, are being dropped, and the volcanic terms used to cover them. For example, andesites and porphyrites are called merely andesites.

THE INDIVIDUAL ROCKS

PLUTONIC.

All wholly crystalline, often coarsely so.

1. *Granite*: The granite family consists of acid rocks. wholly crystalline with a coarse to medium fine grain, and of a grayish or reddish color. Free quartz, in colorless crystals, at times tinged bluish or reddish, is always present. Also a white or reddish feldspar, usually clouded with other whitish substances, and some dark mineral, as brown mica, are to be seen. In some rarer granites only a white mica, besides the quartz and feldspar, is present. The granites are the most easily determined of all the igneous rocks, and can be confused only with one other kind. The feldspar of a true granite contains potash, and is comparatively acid. A rock very similar to a granite, a diorite with free quartz, differs only in the nature of the feldspar, which contains, in place of potash, soda and lime, making it more basic. To the eye of any one but a trained observer, the two rocks appear precisely the same, showing colorless quartz, white feldspar and some dark mineral. This diorite with quartz is called a granite-diorite, granodiorite, or quartz-diorite.

2. *Syenite*. The syenite family may be briefly character-

ized as granites without quartz. They are comparatively rare rocks, especially in the western part of the United States. In color they vary about as do the granites, from shades of gray to pinkish or reddish tints. The minerals are simply feldspar and some dark colored ones, as mica or hornblende.

3. *Diorite.* Of this family the quartz bearing variety, grano-diorite, has already been mentioned. The other varieties are without quartz and more basic than syenites, and have about the same grain as the granites and syenites, though averaging a little finer. The fresh rocks are gray in color typically, but darker than the above mentioned types, and show a white feldspar with some dark mineral, usually hornblende.

4. *Gabbro.* The gabbro family is the most basic of the normal plutonic rocks, which are of complex nature. These rocks are often coarser in grain than any yet mentioned, the individual crystals at times being an inch or so in diameter. In general their color is grayish, often with a dark olive green tinge. Other colors are black, brown, green and in some varieties white. The minerals present are a white feldspar, often with a greenish stain, and some dark mineral which may be dark green, brown or black. Some types are wholly feldspar, and white in color. The gabbros are rare rocks, particularly in this western region.

5. *Peridotites.* These rocks are a peculiar family composed entirely of dark minerals. The feldspars are typically absent, hence the rocks are called ultra-basic, for the dark minerals are usually black, with sometimes a tinge of green. They alter as a rule to the common mineral and rock known as serpentine.

INTERMEDIATE ROCKS.

These rocks, with the exception of the diabases, show what is called porphyritic texture. As far as appearances are concerned, this texture causes the rocks to show well developed crystals of some mineral set in a paste of fine grained material which usually cannot be resolved into its component parts by the unaided eye. This fine grained paste is called the ground mass; the well formed crystals set therein are termed phenocrysts. To the naked eye the different kinds of these intermediate rocks are distinguished by the occurrnce of certain minerals in well developed crystals and also by the color and general appearance of the ground mass.

They are as follows:

1. *Quartz-porphyry.* In this rock are seen crystals of clear colorless quartz, with sometimes feldspar and mica, all set in a ground mass of various shades, from almost black, but subtransparent, through shades of red, pink and grayish. This ground mass varies in grain, from that which looks like an exceedingly fine grained granite to apparently almost glassy. However, as with the granites, free quartz is characterictic. Where the ground mass is noticibly granite-like though very fine in grain, the rock is called a granite porphyry.

2. Porphyry. Often this rock is called an orthoclase porphyry or syenite porphyry, depending upon coarseness of grain. The relations between this rock and syenite is precisely that existing between quartz porphpry and granite. Also porphyry and quartz porphyry are connected in the same way that syenite and granite are. Free quartz is absent, and the minerals appearing as phenocrysts are feldspar, typically the potash variety, orthoclase, with often mica or hornblende. When the ground mass appears fine crystalline to the unaided eye the rcok may be called a syenite porphyry. As a rule the rock looks much the same as quartz porphyry, differing in that free quartz is absent and replaced by white or glassy feldspar.

3. *Porphyrite.* These rocks are the chemical equals of the diorites, but having cooled near the surface, lack their crystalline texture. They are usually much darker rocks than the preceding, showing well developed crystals—phenocrysts—of typically a dark mineral, but sometimes a white feldspar, in a dark gray, dark green, or even black, ground mass. As with the first two types of intermediate rocks, when the ground mass appears finely crystalline we may have a diorite porphyry. These rocks often assume a reddish hue when weathered.

4. *Diabases.* These rocks are the equivalent of the gabbros, occuring typically as dykes and laccolites. They constitute the greatest body of dyke forming rocks known. They are seldom porphyritic, differing from the preceding but are wholly crystalline, appearing on casual observation like fine grained diorites. There are, however, some differences of note. As with the diorites they are composed of a light mineral and a dark one, but the dark one usually has a dark green tinge and a greasy luster seldom present in the black mineral of the diorites. Also, the white feldspar in the true diabases is seen to

be in well formed crystals with the dark mineral crystallized around and between. The reverse is true with the other wholly crystalline rocks; the black mineral shows the best crystal form, with the white feldspar in the spaces between.

VOLCANIC ROCKS.

These rocks constitute the lavas, or surface flows of molten rock. In texture they range from porphyritic to glassy; chemically they cover the same range as the plutonic rocks, from acid to basic. The common term "obsidian' means a volcanic glass of any chemical constitution whatever. Being cooled lava flows they often show what are called flow or fluxion lines. Their varieties are below, and it is to be remembered that these names are now used to cover both volcanic and intermediate types of rocks.

1. *Rhyolite.* These rocks are the most acid of the lavas, corresponding chemically to the granites. In color they are usually various shades of white, gray, blue, pink or green, but are always of light tints except the obsidians, which may appear dark. When porphyritic, they look like quartz-porphyries, into which they shade by insensible gradations, always showing free quartz. When no crystals of any kind are to be seen, yet if the rock is not all glass, their typical white or whitish color serves to distinguish them. The old term felsite is often given to these white varieties which are too fine grained to show any well formed crystals.

2. *Trachyte.* The trachytes are much like the rhyolites in appearance, but differ in showing no free quartz. The only minerals showing are typically white or glassy feldspar with sometimes a small amount of the darker varieties. They have usually a characterictic rough feel, hence the name *trachyte,* which means rough. Specifically, their color is often white, varying to shades of pinkish white or green. The whiteness is more pronounced than in the rhyolites because of the absence of glassy quartz. The trachyte obsidians, like the rhyolitic ones, are darker, often black in large fragments. The family as a whole is a rare one.

Andesite. This family of rocks is much darker than the two volcanic groups already mentioned. The color ranges from a fairly light gray to a black, a dark gray being an average hue. The well formed crystals—the phenocrysts—show both light and dark in color. Some andesites show black crystals in a light gray ground mass, while others show white feldspars in a dark gray or black ground mass. In some varieties the feldspars are glassy, resembling quartz on cursory inspection. Quartz does occur in one variety, known as dacite This rock bears the same relation to an andesite that a quartz-diorite does to a diorite. At time an andesite shows no crystals to the unaided eye, when its color is nearly black, much like a basalt. A noteworthy fact is that these rocks tend to weather a dark red color, due to the iron oxide formed by atmospheric agencies.

4. *Basalt.* These common volcanic rocks are prevailingly black or nearly so. They show discernable crystals less often than the above types, and are usually finer grained and more homogeneous in appearance. However, in some common varieties small grains of a light greenish mineral appear on close inspection—the mineral olivene—and again, at times crystals of black color are apparent in the dark ground mass. A feature of these rocks and of the andesites as well, is the weathering or spliting into so-called "basaltic columns.' The rock mass parts or cleaves into long prisms, roughly hexagonical in cross section, forming a cluster of natural columns.

5. *Limburgite.* This rare and unimportant family of volcanic and intermediate rocks is mentioned merely to complete the account of the massive igneous rocks. This family is composed entirely of dark minerals set in a paste of the same or of glass with identical chemical composition. The color therefore is black or greenish black when fresh, weathering to a dark red.

THE TUFFS AND AGGLOMERATES.

Thus far have been listed only the massive igneous rocks; there is a minor group of rocks formed by fire agencies, of much less geological importance, but of considerable value as building material. This group is constituted by the fragmental igneous rocks, or tuffs and agglomerates.

1. *Tuffs.* These rocks are volcanic ashes and cinders more or less consolidated into firm stone. They are composed of finely divided glassy substances, rock fragments of the various igneous rocks, and often with mineral grains and large pieces of stone. They are named in accordance with the chemical family to which they belong. Thus, there are (1) rhyolite tuffs; (2) trachyte tuffs; (3) andesite tuffs, and (4) basalt tuffs. The rhyolite tuffs are most common.

2. *Breccia.* This variety of fragmental rock is composed of pieces angular in shape and varied in size, usually of only one kind of rock. They differ from tuffs in that they are not ashes, but made up of rock fragments of some size, and have originated either by the explosive action of a volcano or the crushing effect of pressure exerted in the earth's crust. The fragments are usually cemented by a paste of the same material, finer in grain.

3. *Agglomerate.* This rock is most simply described as a mixture of various kinds of volcanic rocks in the form of semi-angular or rounded boulders, small pieces and even ashes. Many agglomerates are hardened volcanic mud containing stones like plums in a pudding. The term is *agglomerate,* to distinguish it from *conglomerate,* which latter term is applied to consolidated gravels deposited by water. Both names mean, however, a mixture of materials.

THE ATMOSPHERIC ROCKS.

This grand division of the rocks embraces those which owe their formation, directly or indirectly, to the decomposing action of atmospheric forces on previously existing rocks. Their structure is that called stratified, meaning in beds or layers. The whole division is often called the stratified rocks. But as all the varieties are not truly stratified, the term is not all embracing. In general there are two primary divisions of these rocks, of very unequal importance. They are as follows:

I. Eolian or wind formed rocks.

II. Aqueous or water formed rocks.

1. *Eolian rocks.* These rocks are of no importance in the present connection, and will be dismissed with a few words. They consist mainly of those materials piled up by the wind, such as the sand dunes of our coasts. Their recent deposition and geological youth prevent any great amount of consolidation, hence the group needs no further mention.

2. *Aqueous rocks.* This group is often called the sedimentary, because they are largely composed of sediments deposited by water action. The name is misleading, for they are not all sedimentary in origin. It can be stated, however, that they have been deposited in or by water. The materials composing them are (1) the residue from the waste of other rocks and derived directly from them; and (2) that material derived

from other rocks by their decomposition, held in solution in water, and deposited either by the action of living organisms or by chemical precipitation. Therefore under this head come two divisions:

a. Sedimentary Rocks.

b. Organic and Chemical Rocks.

Under the action of the atmosphere a rock breaks down into soft incoherent material by the leaching out and removal of its soluble parts, leaving an insoluble residue. Thus a granite disintegrates into a sandy soil, mostly quartz and feldspar, moistened with alkaline water. Ultimately nothing is left but quartz and clay, stained with iron oxide and containing water alkaline with potash, soda and lime. In general it may be stated that quartz and clay are the two least soluble minerals commonly encountered, and hence, singly or together, mark the end of the decomposition of any rock. It is to be noted that from all rocks except the most acid lime is washed out as well as potash and soda, and the more basic the rock usually the more lime. The alkalies play no particular part in rock building but the lime does. Hence in this brief and popular exposition it may be considered that a decomposed rock will yield quartz sand, clay and a solution of lime. The metallic oxides, such as iron and manganese, reman as coloring materials merely, and are of no essential importance. However, as few rocks break down into their ultimate products before being consodidated into new rocks, we may expect to find, and do find, nearly all aqueous rocks to be neither pure quartz, pure clay, nor pure lime. Keeping these few facts and causes in mind, the principle varieties will illustrate their results.

SEDIMENTARY ROCKS.

1. *Conglomerates.* These rocks are consolidated gravels, resulting from the wear and tear of waves and currents upon preexisting rocks. The material composing them consists of rounded fragments of various sizes, often cemented by finer material of like nature. These pebbles or boulders, as the case may be, are often of various kinds of rocks, while again they may be all of one sort.

2. *Sandstones.* The name of these rocks explains their nature; a stone built up of grains of sand. The ideal sandstone is composed of grains of pure quartz, representing the last stage

of decay of preexisting rocks. But as most sand is not pure quartz, neither is most sandstone of pure quartz grains. As a result, these rocks have a variety of colors, depending upon the materials present. The most common minerals are quartz, feldspar, mica flakes, garnet and many other dark kinds. There is also another important quality of sandstones. Such rocks are composed of a mass of grains of sand, set in and cemented by some other substance. The three important cementing materials are (1) silica or quartz; (2) lime, and (3) iron ozide. Combinations of these may occur. The first will give a more glassy appearance to the rock and the color will be nearest to that of the original sand grains. The second will give the rock a white color as a rule; the third will give the stone that red color so desired for architectural purposes.

3. *Clay Rocks.* The one rock name necessary to name under this head is *shale.* A clay or mud, when hardened by natural processes, becomes a shale. A pure clay makes a pure shale; a sandy clay a sandy shale, and so on, with all gradations into the sandstone. These rocks are of no value whtever for the purposes of this report, but the clay rocks mentioned under the last grand division of the metamorphic rocks, the well known slates, are very important.

ORGANIC AND CHEMICAL ROCKS.

There are only two varieties of these rocks of any particular value in this discussion. They are these:

I. Siliceous Rocks.

II. Lime Rocks.

Both owe their origin to the fact that certain minute animals secrete either lime or silica from the water, and on dying their remains accumulate in certain places to form rocks. Also chemical reactions play a part in accumulating both kinds of substances. The first, or siliceous rocks, are formed largely by the growth and depth of certain low forms of life, as sponges; the second are due in large part to the well known coral polyp.

1. *Siliceous rocks or cherts.* These rocks are very fine grained, sometimes almost glassy in appearance, and of various colors from white to red, green and black. They are well known under the name flint or chert. The fact that they are seldom pure silica results in their various shades of color. They are of

no use as building stones, but some have achieved success as road metal.

2. *Lime rocks or limestones.* Under this head come the limestones, so well known to everyone. In color they vary from a pure white through the grays to a dead black, the black being due to carbonaceous material. The texture varies from a medium coarse grain to very fine or compact, that is, showing no crystal forms to the naked eye. The crystalline varieties are least common, and are not marbles, which are metamorphic rocks. The crystals of the limestone are due to simple solution and redeposition, while the marbles owe their crystalline texture to other causes. A drop of a weak acid will always serve to identify the lime rock, as a bubbling of gas is caused.

METAMORPHIC ROCKS.

In this division is treated those rocks which have been changed from their original condition by heat and pressure into new forms. They are derived from both the igneous and atmospheric rocks. Geologically they constitute an extremely important and interesting class; economically they are of little value. A few statements will serve to distinguish the main types. They will be taken up in the following order:

I. Gneisses and Schists.

II. Slates and Quartzites.

III. Marbles and rocks altered chemicallly.

GNEISSES AND SCHISTS.

The gneisses are usually rather coarsely crystalline rocks which show a laminated or banded structure due to a flowage under pressure. In mineral content they correspond in most cases with the plutonic rocks, differing from them in the evident structure. A few varieties are derived from the atmospheric rocks, as conglomerates and sandstones. The banded structure is made evident by the arrangement of minerals in more or less parallel planes. The colors vary precisely as do the colors in the rocks from which the gneisses have been derived. The different varieties are named in a general way from the rock from which the gneiss has originated or resembles most closely. For instance, there are granetic gneisses, syenitic gneisses, conglomerate gneisses an so on.

The schists are similar to the gneisses in that they are banded or laminated, but differ in that these laminations are much finer, giving the rocks the power of splitting along fairly parallel planes. With an elimination of fine distinctions, then the schists are finely laminated·or foliated rocks rather fine in grain, with mineral content roughly parallel to that of the gneisses and hence to the plutonic rocks. Their most obvious difference from the gneisses, into which they grade, is in their finer banding. In color they range from white, in the quartz schists to black in the basic varieties. They are named from the dominent mineral showing, which minral is usually arranged in more or less parallel layers, and causing the rock to split readily along these planes. The schists are derived both from the igneous and the atmospheric rocks. The two chief varieties are the mica-schists, showing bands of brown, black or white mica, and the hornblende-schists, otherwise called amphibolite-schists or greenstones. None of these are of particular value in this paper.

SLATES AND QUARTZITES.

When an ordinary clay rock, or shale, is squeezed under pressure, as often happens in mountain regions, it is made to flow at right angles to this pressure. Certain molecular changes set up in the mass cause it to assume a structure which results in its splitting easily along parallel planes into thin slabs. This structure is called slaty structure, the cleavage is slaty cleavage, and the rocks themselves are slates. They are formed in similar manner from igneous rocks also. The typical slate is not crystalline; some varieties show incipient crystallization and shade by insensible gradations into the schists. Their economic importance is too well known to need discussion.

The quartzites are rocks composed chiefly of silica, or quartz. They have usually been derived from siliceous rocks, as quartzose sandstones, by the addition of more silica, binding the whole into a hard, compact mass. Geologically no, old sandstones frequently are converted into quartzites by long continued action of heat and moisture. Quartz schists and quartzite gneisses, and, in fact, all metamorphic rocks mainly silica, come under this head.

MARBLES AND CHEMICALLY ALTERED ROCKS.

The marbles, properly speaking, are those rocks which have been derived by the crystallization of the limestone by the action of heat and moisture with perhaps pressure. They are ofter of coarser grain than the crystalline limestones. The pure varieties are white in color, composed entirely of lime, or lime and magnesia. When made from impure limestones the impurities crystallize out as other minerals, of varying shades from white through reds and greens to black. The purer varieties of marble, which are of value for ornamental stones, are of even grain, the crystals showing shining faces. The test with acid always serves to identify these rocks. It is to be noted that there are two kinds of limestones; (1) those composed entirely of lime, and (2) those composed of lime and magnesia. The second, or lime-magnesia rocks, are called dolomites, or dolomitic limestones, when only a small percentage of magnesia is present. In appearance there is usually no differense; the dolomites are less acted upon by a cold dilute acid.

The *serpentines* are a group of chemically altered rocks of light or dark green to greenish black color, and usually of very fine grain. Sometimes well formed crystals with shiny surfaces are seen set in the finer material. These rocks have resultd from the chemical addition of water to the peridotiles, or ultrabasic plutonic rocks. They are of some value as ornamental stones.

Steatite, better known as talc and soapstone, is also a chemically altered rock, similiar to serpentine. In color the pure varieties are greasy white, often with a light greenish tinge. They are best known by their greasy feel. Other types of these altered rocks exist, but none of importance in this place. Steatite is often used for furnace foundations and other places where a fire proof material is needed.

This subject of rock classification **is one** of great complexity and difficulty, particularly in regard to the grand division of the igneous. Necessarily the matter has been presented as one concerned with hard and fast rock varieties, with more or less fixed differences. This is not so, for there are no well defined lines separating any of the various rock types, yet after all, it *is* the *types* which are of particular value here, and not the finely drawn conditions and conclusions of petrography.

CHAPTER III.

QUALITIES OF BUILDING STONES.

This chapter is divisable, by reason of its nature, into three parts. One speaks of the qualities of a certain stone, with its consequent value for architectural purposes. These qualities are of value, first, because of the inherent power of the stone to resist those changes which tend to impair its usefulness, and second, because of the resultant appearance of the rock. These characteristics are estimated in a number of ways. Hence, the divisions of this chapter are as follows: First, an account of the many possible changes to which a building stone may be subjected; second, a description of the features which govern these changes; and third, a brief notice of the ways in which these these qualities are estimated. The treatment of all this will be brief, a full discussion being reserved for a detailed report to be issued at a later date.

CHANGES IN ROCKS.

These will be discussed under the following outline:

A—*Physical Changes,* due to

- I. Temperature changes.
- II. Mechanical wear and tear.
- III. Effect of pressure.

B—*Chemical Changes,* due to

- I. Atmospheric solution.
- II. Decomposition of certain minerals.

PHYSICAL CHANGES.

I. *Temperature.* The results under this division are of two sorts, and due to different qualities in any particular stone The first are those results produced by the alternate expansion and contraction of a rock, and, of course, of its component minerals, due to heat and cold. This process is the most important method of rock disintegration in regions of little moisture, as in our typical deserts of the west. During the day the stone becomes warm, or even hot, and expands. At night the temperature lowers, the stone contracts, and the changes being usually rather sudden and of unequal amounts in all directions, chips of rock fly off. The Indians use this principle in manufacturing arrowheads. After heating a suitable fragment in a fire, by touching any desired portion with a drop of cold water, unequal contraction is produced and a small piece chips off. In regions of equable temperature, as along the western coasts, little is to be feared from such action; in Nevada, where the daily changes are often pronounced, some importance is to be attached. The mineral composition and texture of a building stone largely determine how greatly it shall be so acted upon. The loose textured fragmental rocks suffer least, because of their ability to take up without rupture small inequalities of motion in their mass. The massive igneous rocks suffer most because of their internal rigidity and the fact that each one of the constituent minerals expands and contracts differently from the others. The volcanic or partly glassy igneous rocks are probably most liable to such disintegration, the plutonic, because of their interlocking grains, are less so.

The second result from temperature changes is due to the freezing of included water. All rocks are porous to a greater or less extent, the crystalline least of all and the fragmental most so. Also the tendency of all rocks to break into large fragments or masses, often rudely regular in shape, by means of parallel cracks, or joint planes, as they are called, allows water to act in this way. The massive rocks especially are subject to jointing action, which may be either on a large scale or a very minute one. In some instances these joints become apparent only on the weathering of the stone. Water, penetrating the free spaces and cracks in rocks on freezing expands, and exerts a tremendous force acting to disrupt the material.

2. *Mechanical wear and tear.* The conditions under which a stone is to be used determines very largely the changes coming under this head. Stones for paving, for tiling, for floors, and for walks, all must be chosen to resist the constant wear of pressing feet and vehicles. Rocks for curbing, subject to hard knocks and the rubbing of wagon tires, must be had resistant to such abrasion. Such stones should be homogeneous and without flaws, otherwise disastrous breakage may occur. Two less important considerations in this connection yet of too great value to omit, are (1) the action of wind, bearing sand and other particles, on the rock of a building; and (2) the erosive and wearing effects of water, particularly in a country of consdierable rainfall. The hardness, toughness and texture of a building material govern its strength or weakness, of which more will be stated further on.

3. *Effects of pressure.* The most important consideration here is, obviously, the fact that a stone selected for purposes of construction must be sufficiently strong to withstand all the force applied to it. For buildings not of large size the average stone has strength far above that required; in large structures some attention must be paid this factor of utility. The effect of pressure or strain on a rock is that of crushing, each variety of building material having its own crushing strength, as it is called. These figures, expressed in pounds per square inch mean the force necessary to crush a cube one inch on an edge. Some average figures are as follows:

Granite—15,000 to 40,000 pounds per square inch.

Volcanics—10,000 to 30,000 pounds per square inch.

Marble—15,000 to 25,000 pounds per square inch.

Sandstone—4,000 to 8,000 pounds per square inch.

Tuffs—2,000 to 6,000 pounds per square inch.

Results both above and below these are often obtained, the hardest granite and rhyolite showing a strength of about 50,000 pounds per square inch of surface, while other varieties will crush at a pressure of 10,000 or 12,000 pounds, or even less. In use, a factor of safety, usually of from six to ten, is employed. But there is more to the crushing strength of stone, however. An important relation exists between the strength of a building material and its structure. A limestone or sandstone, for instance, is much more able of sustaining a given load when laid parallel to its bedding plane. It is a well known tenet of the masonry trade that a stone should never be laid on edge, particularly one of the sedimentary or laminated rocks. The same holds good in the other rocks, even seemingly structureless granite, for there is often some one direction in which such a rock will cleave or break most easily. This plane should always be laid at right angles to the direction of pressure. Lastly, there is a further consideration growing out of all these facts. All stones are brittle, hence must be handled carefully to avoid shattering. The most incipient fractures, of microscopic dimensions, will in time ruin even the hardest rock. Quarrying should be done by the most approved methods, so that this danger of ruining future buildings shall be reduced to a minimum.

CHEMICAL CHANGES

1. *Atmospheric Solution.* Under this head comes the mere dissolving out and carrying away of certain parts, or the whole, of a rock. The chief agent of atmospheric action is carbon dioxide or carbonic acid gas, which in time decomposes nearly every rock forming mineral. Marbles, limestones and such rocks dissolve completely. Other rocks, as granite, have certain elements leached out, causing a crumbling of the remainder. The alkali metals enter into minerals and compounds which are easily extracted by the water. The decomposition of granite into sand composed of quartz, feldspar and other mineral fragments has been mentioned under the atmospheric rocks. The densest and least porous of the rocks are obviously least libable to this action of solution, and a compact marble, if not broken or shattered in any way, resists for a long time the attack of the atmosphere. In the igneous rocks the iron bearing minerals are easily acted upon and partially leached out. Hence the mineralogical composition of a stone has an important bearing upon its commercial value.

2. *Decomposition of certain minerals.* Here will be briefly outlined some noteworthy results produced by the decomposition of certain minerals. The oxygen and water vapor of the air, combining with the sulphide minerals, such as ordinary pyrite, produce sulphuric acid and iron oxide. This strong acid rapidly attacks the minerals with which it comes in contact, while the iron oxide stains the rock a yellowish or reddish. Pyrite is common in all rocks, and lessens their value for structural purposes in proportion to its relative abundance. An abundance of iron in any rock will cause it in time to become stained a dissagreeable yellow color. There are many other reactions of a similar nature, but of subordinate importance and do not need mentioning. The ultimate value of a stone is greatly influenced by these considerations.

II. ROCK CHARACTERISTICS

1. *Color.* This feature of a stone is governed by the colors and relative amounts of its component parts and minerals. For instance, a granite is gray because of the blending of the black mica, white feldspar and colorless quartz. The value of a stone is largely governed by its color, irrespective of other characteristics. Other things being equal a red sandstone will be more sought after than a dull gray one; a red granite will often com-

mand a higher price than one with a somber hue. The variation in tint of any particular rock also changes its commercial value, as uniformity in all things is desired. Many stones, otherwise first class, are denied a place in the market because of such a defect. Besides the variation in color of a stone from one point to another, it is also to be noted that on drying or mere exposure to the air, some change in the tint may occur. This may be a deepening of color due to partial oxidization or surface chemical change; again it may be a bleaching due to drying. Often a rock with an abundance of iron assumes a reddish or dark red hue, due to the deposition of iron oxide throughout. Many of the Nevada andesites now used in construction are thus altered. The color is pleasing to the eye, but the stone is weakened in the process. Sometimes it is less a change of color than a decrease in the luster of a rock surface. This effect is common on granites, whose materials become either slightly altered on thier exposed parts, or covered by a film of dust.

For ornamental work, as in cornices and monuments, the ability of a stone to show a contrast between the appearances of its polished and rough hewed surfaces is of great value. The crystalline rocks possess this power in the highest degree, because of the fine polish possible. When such materials are carved and their exteriors smoothed, the contrast lies in the fact that a broken surface reflects more white light, while the polished surface, which exhibits the colors of the minerals, absorb more of the sun's rays. A certain granite, valuable as a building material and monumental stone, polishes a very dark gray, while roughing to a light or whitish gray tint.

The selection of color is mainly from two standpoints: taste or fashion, and utility. In regard to taste, there is nothing to state from the view point of this paper except that, other things being equal, a warm tint is preferable to a colder one. Concerning utility, it needs to be emphasized that certain colors are more suitable for particular localities, as, for instance, a gray sandstone should be selected for a building in a manufacturing center, where smoke, dust and grime are ever present. And on the other hand, white stones should be used only where least exposed to tarnish.

2. *Hardness.* The hardness of a stone is its resistance to abrasion, shown usually by resistance to rubbing. Necessarily, the most important characteristic of a rock underlying this is its mineralogical content, a rock containing an abundance of the

harder minerals, as quartz, being the hardest, and, as all minerals vary in hardness, their relative abundance, state of aggregation, and size of crystals, govern the resistance of a stone to abrasion. A sandstone composed of grains of hard quartz may be very soft because of the loose hold they have upon one another. The chief reason for the greater hardness of the plutonic rocks is because their component minerals mutually interlock and bind the whole firmly together. Also in the metamorphic quartzites, the little broken pieces of quartz have grown by the addition of more silica until a similar interlocking texture is produced. A sandstone cemented by lime or iron oxide is softer because the grains do not bind one another together. In all the sedimentary and laminated rocks variations in hardness may occur in the different layers or laminae caused by a change in any or all of the conditions of the minerals mentioned above. As a result, much care must be exercised in their use. In the crystalline and more brittle rocks it must be kept in mind that even the slightest shattering by improper handling lowers the hardness and hence the value.

3. *Strength.* The strength of a stone is its resistance to applied pressure, either compressive force or transverse strain. This quality is very closely allied to hardness and depends in general upon the same internal conditions: mineral content, state of aggregation, and size of grain. As has been pointed out under "effects of pressure," in large structures the power of a stone to sustain a load is of great moment, while in small buildings and other ordinary uses, it matters little. It is not an unusual sight to see in large stone structures that the material near the base shows undoubted signs of crumbling, due to an overload. Every edifice erected is constantly jarred, and this small inappreciable motion has its lasting effect upon a rock already taxed to sustain a weight too near the limit of safety. More facts pertinent to this matter have been mentioned under "effects of pressure."

Another characteristic of certain building stones has a direct bearing on both hardness and strength. It is the power of some rocks to harden, or temper, on exposure to the air. In particular, some of the tuffs show an ability to temper to considerable hardness, at times sufficient to turn the edge of an ordinary hammer. The last bit of interstitial water of the rock, on working its way out to the surface, deposits whatever it holds in solution in the outer parts of the mass, and at times a perceptable crust is formed, which, when broken through, exposes the softer stone beneath. Hence a rock once laid and undergoing this process of tempering should not be disturbed.

4. *Structure.* Broadly speaking we have massive rocks, such as the igneous; stratified rocks, as the sedimentary; schistose rocks, and so on. These are, properly speaking, rock structures. There are, also, other structures of the utmost importance. Joints, which have already been mentioned, are common. Irregular cracks and openings of all sizes, down to miscroscopic joints produced by movement and pressure, come likewise under this head. All these determine very largely just how long a stone will last under given conditions. The massive rocks, those whose characteristics are constant in all directions, are best fitted for long life; the stratified or laminated ones are liable to allow rather free access of water, with resultant deleterious effect, especially if not laid properly.

5. *Texture.* The texture of a rock enters largely into the various factors which govern its strength and resistance to change. The different textures, or internal arrangements, have been stated under rock classification, so that but little in the way of reiteration is needed here. A knowledge of the size, arrangement, and mutual relations of the minerals or parts of a rock are of the utmost value in estimating the worth of such material for structural purposes. For reasons given, a porous sandstone is weaker than a more compact one of the same composition, and should not be used in work requiring any particular strength. In the fragmental rocks the value of the cementing substance is all important. As a general rule it may be stated that the hardest rock is that in which the binding material is of the same nature as the mass. The texture of the plutonic rocks is commonly spoken of as "granitic," because of the similarity with that of true granite; an interlocking mass of crystals.

6. *Mineral Content.* Very little can be written at this time about the various rock forming minerals, because no knowledge of the subject is assumed on the part of the reader. To enter upon a thorough outline of such a matter is beyond the scope of the present paper, and will be reserved for a later date. Quartz, feldspar, mica, and hornblende have been referred to, because they not only are commonly known, but also are among the most important. The importance of the mineral content has been conclusively shown already in the several connections, so that no new space need be devoted to the subject.

III. OBSERVATIONS ON ROCKS

1. *Quarry.* From the quarry one learns the color of a rock, or its colors, as the case may be, its hardness, structure, weight, and something about its texture. Also, the main minerals may be determined with the resistance they offer, severally and collectively, to the atmospheric agents of dcomposition. The ability of a rock to temper well, the colors of the rough and polished surfaces, with much about the larger features, can be ascertained. The weathering effects often show important things. All incipient joint planes, all lines of weakness, all traces of lamination, which are not noticed in the fresh stone, are brought to light in the slightly altered portions. Changes in color are caused in like manner, due both to bleaching, and to staining by the decomposition of particular minerals. Lastly, the quarry shows unmistakably the average character of the rock and not alone its best specimens, and the amount possible to expect for commercial purposes. Quarrying in some of its details, is much like mining The owner almost invariably selects the best piece of rock to be found to exhibit—and who can blame him—with the result that often totally erroneous ideas may be conceived and ultimate injury done to a good business proposition.

2. *Buildings.* This is an important means of determining the value of a given material. It is not, however, as some think, the best or only means. A stone which has proved a failure in one building may owe its poor showing not to inherent weakness, but to a number of various causes, of which the most common are the improper working of the rock preparatory to laying, and the lack of consideration regarding the qualities demanded by the structure. The permanence of color and temper, the power to withstand the attacks of the wind and dust, the effect of sustained load, in a word the *permanence* of the material, may be largely ascertained by these observations. In such estimations it is to be borne in mind that many things must be regarded as influencing deterioration. For instance, some buildings are more exposed than others to all sorts of active agents, as the acids in manufacturing districts. And in every case there are multitudinous little details which every fair minded observer should notice. No stone should be condemned because of one or two failures, as in this way a blow is dealt an important industry.

3. *Chemical.* Since the decomposition of any building material is strictly a chemical process, a knowledge of its chemical constituents, and hence properties, is necessary if we would thor-

oughly understand it's fitness for use. In investigating this quality of a stone we need simply to apply chemical principles to the determined composition in order to throw light on possible alteration. For a simple example, a sandstone ninety-six per cent. silica is obviously far more servicable than one containing fifteen per cent. of lime. A type analysis will be found under granites in chapter IV.

4. *Physical Tests.* These are of several kinds, all of fundamental importance, and serve to fill out the knowledge gained by the methods already mentiond.

a. The strength of a stone is measured directly in a testing machine by applying force to carefully cut blocks. Commonly two inch cubes are crushed, the figures obtained being corrected to ultimate crushing strength per square inch of surface. The machines used are those employed in the testing of strengths of materials in engineering laboratories. The Nevada State University is not yet equipped with such apparatus, which is one of the main reasons for the incompleteness of the report. Such a machine, with a limit of 200,000 pounds pressure costs in the neighborhood of $10,000. The transverse strength is tested by using a suitable prism of stone, laid crosswise on supports.

b. The specific gravity of a stone is the ratio of its weight to the weight of an equal volume of water. The common term "weight" is used in practice, and is similar but not the same, as "specific gravity." For instance, a cubic foot of water weighs about 63 pounds, and its specific gravity is, of course, 1 (one) The specific gravity of a granite, let be assumed, is 2.65. Hence its weight per cubic foot, were it absolutely solid, would be 63x2.65, or about 225 pounds. As a matter of fact, the porousity, or air space, reduces this figure, which would be about 175 pounds weight. To obtain this figure, a simple and fairly accurate method is as follows. A representative piece of the rock to be tested is obtained, say containing about four cubic inches. This is thoroughly cleaned of all loose particles, dried at 110 deg. Centigrade, and carefully weighed in air. It is then suspended by a hair in boiling distilled water for at least an hour, and after cooling to the temperature of the air it is weighed in the water. The difference in the two weights gives the weight of an equal volume of water, which, divided into the dry weight of the stone, gives its specific gravity. The boiling is to drive out all enclosed air which is never done completely, so that the results are a little low, yet are satisfactory for the most practical neels. Also the boiling tends to loosen any small fragments not removed, which also lowers the result. The most accurate way is to place the stone in the water under the receiver of an air pump and exhaust the air. This can be done in the more complete laboratories. This statement is to be remembered: the weight of a rock is proportional to the specific gravity, porousity, and water content.

c. The porousity of a stone is obtained in the above measurement by weighing the piece thoroughly saturated with water immediately on its removal from the water in which it was suspended. This gives the weight of the dry stone plus the weight of water absorbed in the pores of the substance. What is desired, the porousity, is the ratio of the open space in a rock to its total volume. To obtain this we divide the weight of a piece by the weight of the same material which would just fill the open places. The first weight of the dry stone is already known, and we obtain the second by multiplying the weight of water absorbed by the specific gravity of the whole. The great importance of this figure has already been pointed out, particularly in regions of great temperature variations and considerable moisture. A stone thoroughly seasoned, however, ordinarily suffers little.

d. The effects of freezing and thawing on a stone, both dry and saturated with water are properly tested under those conditions most nearly coinciding with those actually encountered. A cube of the rock may be exposed, both dry and wet, to the changing temperature of day and night during the winter, for a period of at least a month, and then tested for loss in weight and strength. The action of extreme heat, as in the case of fire, may be tested by heating a fragment to redness in an assay muffle, and noting the effect, first, on cooling slowly and second, on plunging the hot stone into cold water. The loss in strength is tested in the usual way.

e. Lastly, but not least important, much light can be thrown on all the above qualities of a building material by examination under a microscope. Sections of the rock are ground to a thickness of about two hundredths of a millimeter, and mounted on glass slides. An examination under a propery designed microscope shows everything about the minerals: their relative abundance, nature, size, and mutual relations. Also, texture and even structure missed in all the other methods of investigation, may be shown in this way. Yet the life of the stone might depend upon these very things. In short, a microscopic examination puts the finishing touches upon a thorough search after the qualities of a building material, and such a search is incomplete without this investigation.

CHAPTER IV

BUILDING STONES OF NEVADA

In actual amount, Nevada is well supplied with rocks which can be used as building material. At present, with a territory only beginning its true development, comparatively little is used, and few quarries are opened. Were the following list taken only from those actually quarried, a poor showing would be made. It has been the aim to include also those rocks which can easily be made use of at a profit, in order that both capital and attention may be attracted. All throughout the west, a region of first class building stones, the fact remains that the value of imported stone runs annually into the hundreds of thousands of dollars. The reason seems to be that people refuse to take advantage of natural opportunities and to develop their own resources, largely because imported material is easy to obtain and is less common than home products. It is true that the commoner uses of stone, as curbing, abutments and some buildings, are supplied by materials produced here, but for the finer uses a very large percentage of imported stone is placed. The west suffers from a lack of red granite for ornamental work, as in monuments, yet there is some first class rock of this color both in Nevada and California which should be developed. At the present writing, nothing can be given in the way of figures of invested capital, costs of handling stone, wages, et cetera, for the simple reason that they are not obtainable. Not one quarry in the state is working, and except when a lot of stone is needed for some sudden purpose, no work is ever done. Needless to say, the capital invested is at the most but a few hundred dollars, outside the value of the land, hence is not important. The location and the possibilities of building stones are the most valuable part of what follows. Much in this chapter will be of no immediate value; much will be fragmentary, for it is difficult to obtain accurate data throughout. Many of the important qualities of a stone can be determined only after a quarry face has been opened, and as yet the University is not equipped with a testing machine, hence it will be some years before a detailed report can be published.

The rocks will be mentioned in the order given in the classification in chapter II, beginning with the plutonic igneous, or, as they are sometimes called, the "granitic rocks."

PLUTONIC OR GRANITIC ROCKS

Under this division there are several important stones actually in use, and others with first class possibilities. And in classifying these rocks a slight difficulty is presented. Such rocks are called popularly granites. Some of them are granites; others are not, but all are related. The geographical belt lying on the east flank of the Sierra Nevada and along the foothills is characterized by an abundant development of these, all more or less connected in origin, yet varying from those properly termed granites to those of dioritic nature. As a group, chemically they stand between these two types of plutonics, containing an excess of soda over potash, and often considerable lime. Some contain an abundance of free quartz, others show little to none. As any petrographical discussion is here out of place, only a few remarks of this nature will be presented under each rock. The writer hopes to show later, in a petrographical paper, the true relationships of the granitic rocks of this western portion of Nevada. For the present, the term granite will be used exclusively for those rocks showing free quartz.

GRANITES.

Laughton's Station: This stone occurs in the immediate vicinity of Laughton's Station, to the north of the Southern Pacific Railroad track, about five miles west of Reno. Considerable amounts of rough stone have been taken out at the outcrop directly on the railroad, but no real quarry face has been opened. In color this granite is a medium to light gray, with occasional splotches of a darker shade. The rock is abie to take a good polish, quite in contrast to the rough finish. Considerable joint structure is developed on a large scale, sufficient to make quarrying easy, and yet not enough to preclude the possibility of extracting large blocks. The texture is of medium fineness, or grain, in the main phase of the stone, but varies considerably. The normal rock has much more white mineral than dark, but often rounded spots occur which contain a much larger percentage of black constituents. These spots are at times thickly interspersed throughout the main mass; often they are seen as isolated dark centers surrounded by many feet of surface of the normal variety. The minerals to be seen by the naked eye are quartz, feldspar both orthoclase, the potash variety, and plagioclase, the soda-lime variety, brown mica, and black hornblende. The mica is the chief dark mineral in the normal rock, but hornblende preponderates in the dark spots. Under the microscope the orthoclase felspar is seen to be in crystals much larger than those of the other minerals, and is also greater in amount than the plagioclase.

The quartz is not in great percentage. Little or no pyrite is present. As in all granite, the hardness is considerable. The rock is rather brittle, and the crushing strength is medium for a granite, the variation in grain lowering this value. The stone, because of its location on the railroad, is available at once and in large amount. The railroad owns that part of the mass now quarried at all, and can furnish vast quantities when required. Unless a well opened quarry should show a more uniform grade of material, the uses of the stone will be limited. It can be used for ornamental work if no variations in texture are present, and for all the more common demands, such as foundations, curbing, walks and the like it will give satisfaction.

Verdi: In the vicinity of the town of Verdi, which is about ten miles west of Reno on the Southern Pacific railroad, considerable areas of granite exist. Much of it is directly on the railroad, south of the town, along the Truckee river. From Verdi to the south the surface rises steeply for about two hundred feet to a level terrace of granite, with boulders of andesite dispersed over it, the last remains of an extensive flow. Several faults occur on this terrace, with resultant rise of the plutonic rock and increased opportunity for quarrying. No quarrying has yet been done, but the possibilities are surely worth serious consideration. There are two types of granite which will be described.

1. This first type of rock is that which makes up most of the mass. The color is a rich dark gray, with a faint trace of pink, giving as a result a very handsome stone. It is able to assume a high polish, showing quite dark in comparison with the rough surface. As no quarry face has been opened, nothing can be stated about the structure of the rock, except that as some faulting has occurred, joint planes are probably developed. From the outcrops existing, the texture appears fairly constant, there being a slight change in color in widely separate localities. However, the stone seems to be remarkably free from imperfections in this respect. The minerals present are quartz, feldspar, mostly orthoclase, hornblende, and mica. The hornblende is the more plentiful of the dark constituents. The pinkish tint is due to the color of the orthoclase, which is a pleasing flesh color. Quartz is not very plentiful, whereas the black minerals are, hence the dark color of the whole. The sulphides are very small in amount. The hardness and toughness are perhaps a little higher than in the Laughton stone, and sufficient for all purposes. But like the Laughton stone, it is so situated that it is available at any time with lowest

possible cost of handling. An opening to exhibit the character of the mass is all that is needed to show it up properly. For monumental work as well as for all the best uses, this granite should find a ready market, if present indications have much weight.

2. The second variety of granite from Verdi is found at present only in boulders lying on the worn surface of the other. It undoubtedly occurs as veins in the main mass, and should properly be called a pegmatite. These dykes must be of large size, because of the dimensions of the largest fragmens derived from them. A quarry is necessary to outline any facts about the matter. The color is either a light red ground through which are irregularly dispersed black shining crystals of tourmaline, or more rarely, a white ground with the dark mineral. The general effect is very pleasing to the eye, presenting a sharp contrast to the other variety of granite. The texture is peculiar, for the minerals are not at all regularly distributed. The mass of the rock is made up of quartz and feldspar, usually redish orthoclase, through which occur bunches of black tourmaline crystals. The quartz and feldspar are of fine grain, while the black mineral, in coarser crystals, is in spots in size from a quarter of an inch up to a foot or more. The stone will take a high polish, differing little from the unfinished surface in shade. It should meet with favor for some kinds of ornamental work, as well as for building material, if it can be obtained in large enough amount.

Washoe: This ganite outcrops west of the old town of Washoe, on the Virginia and Truckee railroad, and is a part of the great granite mass occurring at the east base of the Sierra. A quarry is opened about a mile west of the town, on land owned by Mr. John Barrett, the stone cutter of Reno. Not a great deal of work has been done, yet the stone has been shown to be of fairly uniform color and grain. The color is a medium dark gray, with a very faint pinkish tinge, lighter than the Verdi rock. There appear to be few or no imperfections in structure debarring the extraction of large pieces for use, but, in common with most of these rocks of the region, the texture varies somewhat. At times splotches of dark constituents occur to mar the even aspect of the surface. Careful selection, however, should eliminate this evil. A good polish is taken, quite dark compared with the unfinished stone. The minerals are quartz, both varieties of feldspar, mica and hornblende. The two dark constituents are about equal in amount while the quartz is sparingly distributed. The sulphide minerals are rare, as in all of these rocks. Both hardness and toughness are fairly high, and should improve as deeper cuts are made in the quarry. This stone is not quite so readily available as those already mentioned, as a haul of a mile to the railroad is necessary. At present the granite is used for monuments and ornamental purposes by Mr. Barrett.

Nearer the railroad, and in fact, directly on it, is an occurrence of volcanic and plutonic boulders, in which are some of granite. This stone is the same as the Washoe granite just mentioned, and is quarried by the railroad for use in culverts, abutments, and the like. Such a source is, necessarily, limited in extent, yet it does sufficiently well for immediate needs. And it may be well to note here that most of the granite now used in and about Reno for curbing, mounting blocks, and such commoner demands, is obtained from the vast quantity of boulders existing in the river wash covering much of the adjacent territory. It is needless to remark upon the cheapness of this source, yet the best quality of material cannot be furnished in such a way, so that the ultimate cheapness is lessened. Only a well opened quarry will deliver the best stone, and when substantial, long-lived buildings are to be constructed, field boulders should never be used unless of exceptional size.

Ophir: This rock is well exposed at Ophir, about a mile northwest of Franktown, on the Virginia and Truckee railroad. A little preliminary quarrying has been done at a point just south of the wood flume, on the small creek here draining down from the mountains. The stone rises up about a hundred feet above the creek, giving some opportunity for working. As yet the solid mass of the granite has not been reached, the quarrying has been done in the more or less broken surface material. The color is the lightest of all those described being, in the average, a very light gray. Some varieties, small in amount, are darker in shade. A good polish is possible, which is little darker than the rough surface. Jointing is well developed, insuring ease in quarry work while not preventing the extraction of large blocks. In texture the rock as a whole varies considerably, though the main mass is fairly constant. Normally the crystals of the component minerals are fine in grain, with longer black crystals sparingly distributed throughout. The minerals of fine even grain are quartz, both feldspar and brown-black mica, the larger black crystals are hornblende. The quartz is very plentiful, giving almost a glassy luster to the rock. Also, many small grains of a yellowish mineral are dispersed rather plentifully. The other varieties are due to the change in the relative amounts and kinds of the minerals present. Some show an abundance of large shining mica flakes with little or no hornblende; some show much hornblende with no mica; and others show a great amount of clear colorless quartz. These, however, are in small amount. This granite is very hard, but more brittle than the others. It's availability is apparent, being less than a mile from the railroad. It's possible uses are limited by it's variation in texture to the commoner ones, such as curbings, mounting blocks, foundations, and pavements, though it's light color might find favor for contrast in monumental work.

Lakeview: This stone is well shown in the railroad cuts south of the station of Lakeview, three miles northwest of Carson on the Virginia and Truckee railroad. The railroad grade winds around a hill composed chiefly of this rock, thus making it possible to obtain vast quantities at a minimum cost. No quarrying of any sort has been done, as the stone is not of the best quality for building needs. The color is a light gray, similar to, but darker than the Ophir granite. In the exposed outcrop many little dots of red are to be seen on careful inspection. The mass of the rock is quite faulted and jointed, but blocks of large size can be taken out, judging by the weathered portion. The texture is rather coarse in appearance, because of the large size of the hornblende crystals: the light colored constituents are of finer grain. The minerals are quartz, feldspar, again both kinds, with a slightly larger percentage of othoclase, hornblende and mica. The hornblende is the chief dark constituent. Quartz in nominal amount. A considerable number of small grains of a yellowish mineral are present, as in the Ophir stone. One other substance is worthy of notice; the mineral magnetite, which shows quite plentiful under the microscope. Such a rock as this is limited in usefulness to the commoner demands, and it is also possible, on account of the mineral content, to use it as a road metal. It's vast amount, easy of access, its small mica percentage and its comparatively large percentage of iron, make it easily possible that it might prove a success as a material for macadamized roads.

Carson Prison: On the Prison Hill as it is called, a granite similar, or the same, outcrops from beneath the andesite flows. This locality is not on the line of the railroad, but is easily approached by teams. If the stone proves a good road metal, this would make a good locality to furnish material for those parts of the region nearby.

Luning: Near the town of Luning, in Esmeralda county and five miles from the line of the Carson and Colorado railroad, there is an occurrence of a fine grained white granite. No real quarrying has been done, and only a small amount of stone has been extracted. Small pieces show a finer grain than in the other granites described, and exhibit a contrast with them. The land and stone is owned by Mr. Lindsay, of Carson, who has the stone for sale, as well as for his own use in building work.

Mason Valley: This stone occurs near Mason Valley, in Hudson Pass, Lyon county, about eighteen miles from the Carson and Colorado railroad. As with most of the other rocks, no quarrying of any amount has been done, and the stone awaits a market. The color is rather striking, being a light mottled pink-gray. On close inspection three distinct colors present themselves, due to the different minerals; white, pink and dark green. The polished surface brings these out well, and presents a considerable and pleasing contrast with the rough finish. The grain is medium and even, with an occasional large white crystal. The polish brings out clearly most of the component minerals. To the naked eye no quartz is present, and the rock looks like a syenite, or that rare rock standing between a syenite and a diorite—a monzonite. The minerals easily seen are feldspar, including stout pink crystals of orthoclase, and long white crystals of plagioclase. Under the microscope, quartz is apparent, making the rock a granite though a basic one. Both hardness and toughness are high. The stone is not as available as could be desired, yet its color and other qualities are such that its value is high. It can be used for monumental work, and buildings, and should find a ready market. The owner of the present "quarry" is Mr. Lindsay, of Carson.

Winnemucca: Two varieties of granite are used in Winnemucca. The first is quarried twelve miles to the north of the town, and hauled in by teams. It is a medium light gray stone, taking a fine polish, and is sufficiently good for the best class of work. The grain is of medium coarseness, with little variation in color or mineral content. The minerals are the usual ones already mentioned, with not a great deal of quartz. By way of illustrating availability, some figures of cost of hauling for this stone will be given, which are fairly good for others removed from the railroads. A trip from Winnemucca to the quarry and return occupies two days, with a large wagon. Seventy-five cubic feet of stone are hauled at a trip, for which eighteen dollars are charged. This stone has found some favor for monuments in the town, and can be used for ornamental and construction work. Mr. Joe Pasquale is owner.

The second granite used in Winnemucca is taken from boulders found on the lower slopes of the mountain bearing the same name as the town. In color and general appearance it is much like the first, but takes a poorer polish. It also has found some demand for monuments and buildings, but is inferior to the first because of longer exposure in fragments. However, it is well adapted to all the commoner uses.

Elko: Much granite exists both to north and south of the town of Elko but at some distance. At present one variety is quarried, and used in the town for nearly all purposes. This rock comes from a spot about thirty miles north, necessitating a long haul. The distance from the railroad limits its use and market, for when a quarry is well opened on the line of the railroad, as can be easily done, at a place like Verdi, such a stone will be driven from use by it's cheaper rivals. It is possible to find some first-class monumental granites in the region about Elko. And there are many other possible stones. Granite is plentiful at Steamboat Springs, and more at Verdi, up Dog Creek Canyon. Likewise in the eastern part of the state there is much similar stone, most of it unknown in value and qualities. But for some years only the most valuable granites existing away from transportational facilities can be available, because of the wealth of easily obtained poorer stone outcropping directly on the railroad lines.

DIORITES

Virginia City: The mass of Mt. Davidson, upon whose eastern flanks Virginia City lies, is chiefly of a dioritic rock. It is not urged that this rock would make a first-class building material, for it's color is a somber gray, it's grain fine, and the whole aspect uninviting. It is mentioned in this place because of its possible use as a road metal. It's constituents are feldspar and hornblende, with usually some iron pyrite. The texture is one of interlocking crystals, causing very great toughness. There are several phases of the stone, each with it's own color and general appearance. The summit outcrop develops a gray granite looking rock; the tunnels and crosscuts in the mines often show a much darker variety. For a road metal, the binding power should be good, while the toughness will be vouched for by every miner who has driven a drill into it. As mentioned in the chapter on road metal, the rock may prove easily a most valuable one for use on roads underlying heavy traffic.

Beckwith Pass: This rock is found near Beckwith Pass, in California, but as its development must come through Nevada, it is here included. Like all the granite rocks, it exists in practically unlimited quantity. A little quarrying has been done, sufficient to show up the stone fairly well. The color is a very dark gray, darker than the Verdi granite, which it somewhat resembles in appearance. It takes a perfect polish, which does not present a great contrast to the rough surface, as the stone is essentially so dark. The grain is of medium coarseness, and very constant; the stone is quite free from irregularities of all sorts. The minerals present are plagioclase feldspar, with mica and hornblende in nearly equal amount. Black magnetite also occurs. The hardness and toughness are fairly high. It is yet necessary to haul the stone some distance to the railroad, which militates slightly against it's use. With the advent of the proposed Western Pacific railroad, this difficulty will be largely eliminated. The quarry now operated is owned by Mr. John Barrett, of Reno, who has been mentioned as owning a Washoe stone. This diorite is now used for monumental work entirely, and is well fitted for all the best class of uses. It also might prove a valuable road material, for which the chippings and waste could find a market.

VOLCANIC ROCKS

RHYOLITES

There are two stones used in Nevada which are classed with this group of rocks. Both are from the region just south of Virginia City, near the American Flat Tunnel on the line of the Virginia and Truckee railroad, in Lyon county. Both are quartz-porphyrites in a general sense, though there are variations from a true quartz-porphyry or rhyolite, to a quartz-andesite, or dacite, based on the nature of the included feldspars. In detail these rocks are as follows:

1. The first stone is quarried from the great mass covering many acres, at a point on the railroad one-fourth of a mile west of the American Flat tunnel. The color is a not unpleasant yellowish white, a suitable shade for a dry, dusty climate. The texture is porphyritic, and even throughout large volumes. On close inspection the color is seen to be due to the ground mass; while the crystals showing are chiefly clear quartz, and white feldspar. Some small grains of iron bearing minerals, as mica, are present in small amounts. The general effect is good, a little different from the usual run of stones. The rather large glassy quartz grains, particularly, give the rock a distinct individuality. The

hardness is high; the toughness a little less, and both rank with the best. Much resistance to atmospheric changes is given, so that long life to a structure of this material is assured. The quarry cut is directly on the railroad, so that any amount needed can be easily obtained, the railroad, of course, owning the land. This stone was much used in the early days on the Comstock, chiefly for foundations. It shows no evidence of change where so used. The railroad now constructs of it abutments, culverts, retaining walls and other similar structures.

2. The second quartz-porphyry is quarried five-eights of a mile east of the tunnel already mentioned. The color in the mass is a medium dark purplish, which color is a not inconsiderable factor in the worth of the stone. The texture like that of the other, is porphyritic, with well developed crystals of quartz, feldspar, and dark mica. The color is due to the purplish-gray ground mass, in which the other minerals show distinctly. The main difference between these two rocks is in the color, and the increase in the amount of mica in the purplish variety. This latter stone is decidedly pleasing to look upon, and should find favor for buildings. It's hardness, toughness, and other characteristics are identical with those of the first of these rocks, and likewise it is quarried by the railroad and used in some of it's culverts and abutments. It has been used in one of the railroad crossings at Steamboat Springs, and makes a fine appearance.

ANDESITES

There are several quite prominent building stones under this rock group, including some of great promise. As the demand for such materials of construction increases, they should all find ready markets, particularly as they are easy of access and near the centers of population.

Southwest of Reno: This stone is the one used largely in the erection of the new Carnegie Library Building in Reno. It is locally called a sandstone. It comes from one of the large andesite flows which bathed the lower eastern flanks of the Sierra in recent geological time. The quarry is situated at a point about four miles southwest of Reno in an air line, though nearly two miles further by road. The work here has just begun, and is due to the construction of the building just mentioned. Enough has been accomplished, however, to show some of the larger characteristics. The quarry shows well the flow structure of the mass; the planes of motion lie nearly horizontal, greatly facilitating the extraction of large blocks. On this account, the cost of quarrying is very low, aided also by the absence of any overburden, or surface waste material, beside a few feet of rocky soil. The color is a medium light red or red-gray, similar to but redder than the tint of the quartz-porphyry from Virginia City. The texture is porphyritic, showing white feldspar crystals with smaller ones of mica and hornblende, in the red-gray ground mass. The white feldspar is all that shows on a cursory examination, and as much of this mineral is present, the popular term sandstone has been employed. These more or less lath shaped crystals of feldspar are arranged roughly parallel along the flow planes. The red color of the ground mass owes it's nature to the decomposition of the iron-bearing ground mass, with the resultant deposition of iron oxide throughout. The effect produced is fair to look upon, but the stone is weakened thereby. The hardness and toughness are low for a rock of this type, and are little better than in an average sandstone. It would crush, probably, at a pressure of about six thousand pounds per square inch. This is sufficient for all ordinary demands, but not enough for the very largest buildings now erected. It will withstand much in the nature of temperature changes, as will all the rocks of this group.

Being situated near Reno, it should be used in many more buildings to be erected in the near future. It's general appearance counts strongly in it's favor.

On the western side of the ridge on which the above quarry is situated, is a second outcrop of the same rock. There is a difference, however, for here the red color is replaced by a gray, due to the non-oxidation of the mass. The other features are the same, except that the lasting qualities are much better. The two stones are in pleasing contrast, and will undoubtedly find favor in a short time.

Huffaker: There are two varieties of andesite at this point, five miles south of Reno on the Virginia and Truckee railroad. The railroad here skirts the foot of a rather low hill, on which outcrop the rocks in question. They are both part of the same mass.

The first is a red stone, a shade darker than the library andesite. It forms most of the surface material and can be obtained in quite large amount. No quarry face has been opend, so that nothing can be told about is structure. It has no flow planes like the first mentioned andesite. It is porphyritic in texture, showing well formed crystals of black hornblende, red discolored lath shaped crystals of feldspar, and all in the red ground mass. The hornblende is quite plentiful, the feldspar is about equal in amount, but decomposed and reddened as is the ground mass. The hardness is medium, the toughness somewhat less. The availability of the material is a strong point in it's favor, as it outcrops less than a hundred feet from the railroad track. It is on the Huffaker ranch, and has been used locally to some extent.

The second variety is a granitic looking rock, and by the average individual would possibly be called a granite. It outcrops on the same hill as the other, and, due to the fact that less decomposition has taken place, lacks a red color. It is a medium light gray stone, apparently showing quartz, feldspar, and hornblende. Careful study, with and without the microscope, show it to be a truly prophyritic rock, of medium grain and even texture. The minerals in well formed crystals are white feldspar, black hornblende, and a few flakes of mica, set in a glassy, colorless, ground mass. It is this glass which has the appearance of quartz. The general aspect of the rock is decidedly in its favor. As no real quarrying has been done, and no thoroughly unaltered rock exposed, it's other qualities are not known. From it's construction it must be a very hard though perhaps brittle, stone. The Huffaker residence, a large two story structure, is made of this material, which shows no change in its thirty years of service. These two andesites are worthy of careful investigation and some work done to exploit them.

Fulton's Quarry: The rock exposed in this place exists to the north of Reno, over considerable territory. The quarry itself, in the best material, is about two miles north of the University campus, just above the line of the Nevada, California and Oregon railroad. What work has been done is all on the surface; no quarry face has been well opened. The color is a light greenish gray in the mass, and a restful one to the eyes, especially in the glare of the sunlight in a hot, dry climate. The rock is rather strikingly porphyritic on close inspection, though of even appearance at a little distance. Large glassy feldspar crystals half an inch in length are frequent. Also, many flakes of dark mica are present, with a little hornblende, and all set in the compact, greenish-gray ground mass. In selected pieces the texture is fairly constant, but as a mass much variation occurs. Inclusions of other materials are found, and small cavities lined with materials are at times plentiful, so that careless work may result in unsightly spots in buildings. The hardness and toughness are fair, and the resistance to weather changes is good. As it is on the railroad, it's availability is excellent, and there is a vast quantity in sight. The stone has been used considerably in Reno. Several of the newer University buildings contain it, as the gymnasium and

Lincoln Hall, and a few structures in the business part of town are made wholly, or nearly so, of the material. It's greenish tinge gives a pleasing aspect to the buildings containing it. Another possible use is that of road metal. In the search for such material soon to come, a test upon the rock would not be ill advised.

Virginia City: About two miles to the east of the old town of Virginia City runs a ridge approximately north and south. Sugar Loaf peak is part of this ridge, which is cut in two by Six Mile Canyon and Creek. An andesitic rock forms this feature of the topography, furnishing one, and able to furnish two, stones for building purposes.

The first of these is quarried at a point just east of the Brunswick Lode, on the east side of a small hill rising from the ridge. Considerable rock has been taken out here, yet in a more or less careless manner, and no well cut face is shown. The structure of the mass is quite remarkable. Rock columns averaging two feet or more in diameter compose the whole, like a bundle of sticks laid carefully parallel to one another. These columns pitch to the northwest at a low angle, aiding very materially the quarrying. This stone is the most striking in appearance of all those described in these notes, and is almost beautiful. Any one word will fail properly to give the color, for the texture has given the rock a mottled aspect. This texture is porphyritic, and large roughly rounded feldspar crystals often half an inch across, with smaller prisms of hornblende and flakes of dark mica appear in a blue-gray, or steel blue ground mass. The feldspar is quite glassy, much in contrast to the lusterless colored ground. There is some variation in texture, which must be guarded against by selecting only the best. Frequently small inclusions with slightly different color and grain occur, which spoil the even effect of the whole. The hardness, toughness, and other characteristics are good, and need little consideration under ordinary circumstances. The stone is easily obtained, the quarry being less than two miles from the railroad, and an easy haul will deliver it at the station. It was used extensively in the early days of the town for foundations for large machinery. As it yet remains in place, one can see how well it stands. To state that it makes a beautiful appearance does not seem like exaggeration.

The second variety of these andesites occurs in Sugar Loaf, and in the exposed places in the immediate vicinity. It has not yet been quarried nor used. A fine exposure is present to the southwest of the road in Six Mile Canyon just where the bridge spans the creek at the base of Sugar Loaf. This rock is very similar to the first, yet distinct in its general appearance. The ground mass is a very light gray, with a faint tinge of blue, and the well formed minerals are white feldspar, in smaller crystals than in the first phase, with black hornblende more plentiful than before, and a little dark mica. The other qualities are about the same as those of the first variety, and are good. A little harder pull by team is required to land it at the railroad yards, yet this will not count much against it. As far as known, this stone has never been worked, but it would make a very good building material.

TUFFS

There are three of these valuable building stones now in use in the state. They are softer than the average consolidated tuff, yet this lack does not prevent their being used in many important ways. They fill a want for certain kinds of materials better than any other stone, and at times rank with the best sandstones.

Merrimac Station: This tuff outcrops in the Virginia Range in the canyon of the Carson river, at Merrimac Station, on the line of the Virginia and Truckee railroad. This point is a few miles east of Empire, and within easy reach of all important points. The quarry, owned by Mr. J. W. Adams, of Carson, is on the south bank of the river, and is one of the very few well opened ones in Nevada. The color of the stone is a light pink, almost a flesh color, and does not vary throughout the mass. As it is composed of volcanic ashes, with some mineral fragments. it's texture might be taken to indicate a very fine grained sandstone. The fragmental character is clearly shown, and the absence of stratification planes or layers indicates to the unaided eye the nature of the material. The ash is largely glass, in minute fragments, in which are imbedded angular pieces of mica, quartz, and feldspar in small amount. The grain is very even for such a stone, and it's general effect is very good. In hardness and toughness it stands low, about equal to a soft sandstone, too low to warrant it's use under much stress. It tempers a little on standing, but not sufficient to raise much it's strength. It is rather porous, as are all the tuffs, yet withstanding temperature changes well, because of it's internal structure. It has been used very largely in and about Carson and Reno, chiefly for copings, cornices, lintels, arches, and such others requiring little strength. When used with brick, a very pleasing contrast is presented, as is done with any other material harmonizing with it in color. The Gymnasium and Lincoln Hall of the University Buildings both contain it, some brick residences in Reno are much improved by its use;

and the new Elk's Hall shows it to advantage. This tuff should be much used for the demands befitting it.

North of Reno: This tuff comes from a mass of consolidated ash almost twenty miles northeast of Reno, on the Spanish Springs Valley road. A little stone has been quarried and used in Reno in ways similar to the Merrimac rock. It's color is a light pink, a little lighter than the first material. These two stones are very similar in their features and can be used in precisely the same ways and for the same demands. This second tuff, however, is more irregular in texture, containing angular fragments of other rocks, largely andesite and granite, thereby appearing somewhat mottled when closely inspected. It tempers slightly better that the other. Careful selection should eliminate the unsightly stone from that quarried. The owner is Mr. Wm. Schrader, of Reno.

Lovelock: This rock is located in the hills to the northeast of the town of Lovelock, on the line of the Southern Pacific railroad. The point from which it has been obtained is about four miles from the station with not a hard haul over the distance. The color is a purplish-gray, of a medium depth of tint. The structure and texture are in general the same as in the other tuffs. Many small fragments of volcanic rocks are interspersed throughout the mass, and small glassy cystals of feldspar are quite noticible on careful inspection. The rock inclusions are dark gray, so that a close view exhibits many seeming imperfections in grain. Used in a building these are not apparent, and the whole aspect is a very pleasing one. The usual shade of purple will give a pretty contrast with other stones whose color blend with its own. The hardness and strength are good, ranking well up with that of the best sandstone, while at the same time it is resistant to atmospheric changes. A vast amount is in sight, and when once introduced, a ready market should follow.

Washoe: A rock similar, yet different, from the three tuffs mentioned, is found at Washoe, on the Virginia and Truckee railroad. This notice is of value chiefly from a historical standpoint, as several of the old abandoned buildings of the once thriving town are made wholly of this stone. In it's nature it is a volcanic agglomerate, or a consolidated volcanic mud, and an unusual material for purposes of construction. The old quarry is on the hillsides above the railroad track just north of Washoe station, in a surface cut only a few feet in the mass. One is tempted to describe it as having a mud color, this feature is so very inconspicuous. More specifically the color is mottled light and medium dark gray, and the surface usually appears dusty The texture is quite porous. Nothing in the way of definite substances or minerals can be easily determined or distinguished. It's lasting qualities rank with an average sandstone, but its strength is less. It is easily available, but its use cannot be urged in the face of much more and better stone.

ATMOSPHERIC ROCKS

SANDSTONES

Nevada has had developed up to the present time only a few rocks of this family, and none of them can be called first-class. They are all of recent geological age, and owe their qualities to their youth. As the development of the state goes on, more such will surely be found, perhaps some of the very best. These stones will be needed as the cities and towns grow, and the best will command a good price.

Carson: The first and most important sandstone is the well known one at the State Prison, near Carson. The quarry constitutes the prison yard, and has had the most work done of any in the state. The sandstone beds or strata occupy the site of an extinct lake, and exhibit the quite famous animal tracks on the present floor. The color is a yellowish-gray, a gray unfortunately, streaked with a light yellow, and not uniform. The rock is rather heavily bedded, with the bedding planes nearly horizontal. This position is probably the same one the stone has always occupied, although slight tilting may have occurred. On this account, of horizontality, quarrying is easily done. That mineral content shows the stone to be derived from the weathering and decomposition of a granite, the yellowish tinge being due to the oxidation of the iron bearing substances. The constituent grains are cemented by secondary silica. The grain of the rock is of medium fineness in the average, but at times becomes quite coarse, containing pebbles up to half and inch in size. The hardness and strength are medium, sufficient for all ordinary needs, and the resistance to other forms of change is good. There is much material in sight at the prison yard. The stone has been used largely in Carson and Reno. The new chemistry building at the University is constructed wholly of it, and presents a very satisfactory appearance. A small amount has found a resting place in the stone entrance to the University grounds, as is shown in the frontispiece.

Fallon: This sandstone occurs near the town of Fallon, in Churchill county. Little quarrying has been done, but samples of the rock show its main features. In color it is a cream white very uniform in the small pieces shaped for exhibition. The grain, too, is uniform, and quite fine. It's hardness and strength are about equal to those of the Carson stone, and satisfactory. It should resist the weather well, and appear to be a very fair stone for building purposes. Mr. L. B. Self, of Reno, is the owner.

Winnemucca: There are two varieties of these stones quarried near and used in Winnemucca. Neither are first-class in any respect, though they do well enough for the local uses. They are taken from the old lake beds, to the northeast of the town.

The first stone is quarried nine miles from the railroad station and hauled in by team. The color is a light drab, and quite uniform. The minerals and substances comprising the stone do not show, on account of the fineness of the grain. Some black flakes of mica are noticible, but nothing else. The hardness and strength are low, too low for anything but the smaller structures and the uses demanding little power to withstand pressure or stress. It stands temperature changes well, and were its strength higher would be an admirable building stone. Some new buildings have recently been erected in Winnemucca composed largely of this stone. Such local uses are well met, but the demand for such a rock will of necessity be limited to the town itself. Mr. Joe Pasquale is owner of the stone.

The second variety of sandstone is quarried from a point four miles from the town, and much more available. However, the quarry has been abandoned, on account of numerous faults and breaks in the material, which render the cost of obtaining stone fit for building almost prohibitive. The color is a light gray; the texture is coarser than in the first variety, and somewhat variable. The hardness and strength are considerably more than in the first, so that were the stone to be easily obtained its use would be wide. New developments later may show different and more favorable conditions. The new fire company house in Winnemucca shows a handsome front of this material. Mr. Pasquale is owner of this stone, as of the first.

Elko: At Elko there is a sandstone much like the first one described from Winnemucca. As with the rest of the soft materials, its use is limited to small buildings, where the strain upon it is light. The local demands are met sufficiently well by it, but it can never have wide use. There is surely much first class building material to be developed in this part of the state as the population increases.

MARBLE.

The marbles in Nevada are well represented, although little has been done to develop them. Only a few are quarried, due, of course, to the scattering demand and difficulty of gaining a market against other stone now used. It should not be many years before a steady market is open to them, not only in this state, but in others as well.

La Moille Valley: On the borders of this valley, in Elko county, exists a vast amount of a fairly good variety of marble. No quarrying has been done, but some stone has been taken out to show its character. The color is white in one variety, and a gray, or a laminated gray and white, in another. The white is clear, not marked by yellowish spots or flaws. The stone is rather finely crystalline, and takes a good polish. The marbles are all hard, brittle, and easily, though slowly, soluble in atmospheric waters, as has been discussed in a previous chapter. The rock is not very far from transportation facilities, and should meet with some demand. The uses are mainly interior ones, such as tiling for floors, mantels, mosaic work, and others. Mr. W. T. Crane, of Lee, Elko county, is the owner.

Humboldt Mountains: In these mountains a considerable amount of coarsely crystalline marble exists, which may prove of some value upon more careful investigation. What rock has been seen shows a pure white color with few impurities appearing on weathering. This is not the only place where such rocks are known to exist; it is cited merely as an instance of the little knowledge regarding these things.

Luning: More marble, of gray and white colors, exists in the region in the vicinity of Luning, Esmeralda county. Some of this has been quarried and used by Mr. Lindsay, of Carson, and it ranks with the others mentioned. It outcrops on the line of the Carson and Colorado railroad, hence is easy of access, which is a strong point in its favor. More facts concerning it are needed.

Topaz, California: Considerable marble is found in Antelope Valley, in California, opposite Douglas county, in this State. As its use and development comes naturally through Nevada, it needs a mention here. The stone varies considerably in color, from white to blue, gray, and yellow. As the locality is off the railroad, the development work has lagged, but the rock deserves some attention in the near future. The uses are those already mentioned. Mr. Lindsay, of Carson, owns much of the material.

Inyo County, California: Considerable marble has been quarried in Inyo county, California, and used both in Nevada and California for tiling, mantels, mosaic work, and such demands. Some of the rock is laminated; most is not, but cracks and flaws are quite common. There are three distinct colors of the marble, white, yellowish-white, and dark gray. The contrast between these is very pleasing to the eye. The lasting qualities are the same as the other stones of like nature possess. The stone works on the Truckee river above Verdi are handling this rock almost entirely and have some large contracts on hand.

TRAVERTINE.

Bridgeport, California: This variety of stone is related to the limestone, having been deposited by springs. A great deal of these deposits are to be found over southeastern California, Nevada, and Arizona, marking the sites of old springs. The only occurrence yet exploited in or near Nevada to any extent is near Bridgeport, in Mono county, California. The stone is a variegated reddish, and yellowish, very handsome when polished. It was used in the new City Hall in San Francisco. The work of exploitation needs to be carried farther, as it will be when more demand is made for the material. Its uses are purely ornamental.

It is needless to say that very many more stones suitable for purposes of construction exist in the State. Only those actually used, and those about ready to be used, have been listed. There are many more known; there are vast amounts to be discovered.

The frontispeice shows a number of the rocks mentioned actually in use in the "University Gates." The large columns supporting the gates are made from granite taken from boulders near Reno. The smaller pillars just outside are composed of Washoe granite, a shade darker than the first. The stone wall exhibits two more. The first, or ground course of blocks in the wall to the left is made of the andesite from the Fulton quarry, north of Reno. The upper three courses of stone are all the Carson sandstone. The finish throughout is rough, and the appearance very pleasing.

CHAPTER V.

ROAD METAL AND SOME GENERAL PRINCIPLES OF ROAD MAKING.

This subject does not come strictly under the head of building stones, yet its vast importance to the welfare of any community, together with the fact that some knowledge of rocks is essential to a proper understanding of it, more than justifies a short chapter setting forth a few fundamental considerations. The bicycle and other horseless vehicles have done one great work, if nothing else; they have shown conclusively to all people the value and immense importance of good roads.

Time was when the old earth road was held sufficient for all needs, and such roads were not even crowned. We still have many earth roads, which, when properly compacted and graded, do well enough for light traffic in sparcely settled regions. Where travel is at all heavy, however, earth roads become a makeshift, and some material which will not cut to pieces is needed. Very naturally, men have turned to rocks to furnish such material, termed in general, "road metal." The roads made by crushed rock on an earth foundation are called macadam, from the name of the man who introduced them.

For the purposes of road construction we have a vast abundance of rocks of various kinds and character. Bearing in mind the classification of rocks in Chapter II, we realize the range of choice. All of the igneous, atmospheric and metamorphic rocks, of hardness greater than earth, might be used. By class the igneous rocks are hardest, the atmospheric, softest; the igneous are more or less crystalline, the atmospheric largely fragmental. The metamorphic rocks are intermediate in their qualities. In Nevada there is a large development of all these kinds, easy of access. But this wide range of choice not only furnishes abundant possibilities, but also allows the selection of the best. It must be self-evident that all road materials are not of equal, nor anywhere near equal value. There is always a best and a poorest for every case. In order to select the best road metal for a certain street or road, a knowledge of the principles underlying such choice must be had. A brief account of these will be presented.

The fundamental fact on which all road making is done is the simple one that a highway is constructed to withstand constant wear. It must first be known, therefore, of what this wear consists. The wasting of a road is due, first, to chemical agencies; second, to physical agencies; and, third, to mechanical agencies.

The chemical agencies are those constantly at work in the atmosphere, and producing (1) solution and (2) decomposition, as pointed out under building stones. The physical agents are likewise atmospheric, and are: (1) frost, producing disruption of the road and of the individual rock fragments; (2) the effects of rain falling on the surface, running off, loosening the road surface and transporting the material away; (3) the wearing effects of the wind in carrying off the fine particles as dust. The mechanical agencies are due to the action of living things; the wearing down and grinding up of the surface; the crushing effect of heavy loads and impact of of the feet of animals; and the possible injurious effects of roots. With roads properly constructed, of those forces tending to impair their usefulness the physical and mechanical agnets are most important.

Enough has been written of chemical agencies under a previous head, so that a mere mention is all that is here necessary. Such processes in nature are so slow that roads suffer little comparatively from them. However, chemical reactions play an important part in the process of compacting, or binding a road-bed and making it durable. This power of binding, or cementing, in a road metal, is an essential quality, and the higher it is the better. All other things being equal, the ideal road material is that one which will furnish a large percentage of mineral, or minerals, that do not alter or which change very slowly, with some other mineral or minerals capable of furnishing, by slight decomposition, sufficient cementing substance to bind the whole together as a solid mass. The particular minerals best fitted to accomplish this end are those containing iron and alumina, with silica. Lime bearing minerals also are valuable. By way of a homely illustration, this process may be likened to a sidewalk made of nails, which, on being allowed to remain for some time, becomes rusted into a solid condition. There are several more important binding materials, as clay, secondary iron minerals, calcite or lime, and sometimes silica. These must form, in order to be of greatest good, in just the right amount to bind the gradually pulverized surface coating, as well as to harden the whole.

Of the physical agencies, in regions of considerable range of temperature, the action of frost may be of some moment. As mentioned under rock weathering, water, entering the pores of a stone and in cracks, on freezing becomes a powerful lever tending to disrupt the material. Also, the mere alternate cooling and warming by daily variation, gradually weakens a rock. In mild climates these things play no part. The effect of rain in loosening and wearing away the road surface may become a source of danger in poorly constructed highways. The greater effect of rain is its power of transporting the layer of fine material necessary on every well kept road. This action is measured by the specific gravity of the minerals composing the rock surface, their shape, and their state of compactness. For instance, mica is a poor miner to have in a road metal, because of its flaky nature which allows of its easy transportation by the rain and wind. The selection of a stone must consider all these points. In like manner the winds are constantly picking up and carrying off as dust the lightest rock flour from the surface, often sweeping the streets clean of loose fragments and depositing dust over nearby houses and vegetation. Thus, the rain and wind, together or singly, are mainly responsible for the loss of that layer of finely ground rock which should constantly cover the top of every road and street a small fraction of an inch in thickness.

The mechanical agencies are the most easily seen, and are chiefly the grinding and pounding of the travel over the highways. The pulverized surface is thereby constantly loosened ready for the wind or rain, and just as fast as this disappears more is worn from the underlying rocks to replace it. Also, if the mass of the road be not well compacted, it will loosen, tending to form "chuck holes." Obviously, the heaviest traffic will do the most damage, and will be the most difficult to meet. The disrupting effect of roots should be reduced to nothing by a proper construction of the road bed.

Keeping these considerations in mind, it can be seen that a choice of road metal is made by considering for every case (1) the requirements which the road must fulfill; and (2) the power of given materials to meet these conditions. In any one locality the mechanical wear and tear is all that varies appreciably, the rest remaining practically constant. In other words, the traffic changes from place to place, so that we need harder and firmer highways in a city than in the open country. These five divisions of traffic are commonly made to denote this: City (perurban), urban, suburban, highway, and country road. City traffic is that existing on the streets of large cities, and no ordinary macadam can withstand it. Stone and wooden blocks, asphaltum, vitrified brick, and some few other substances are commonly used. Urban traffic is that common to city streets not used for continuous heavy teaming. The hardest and toughest macadam must be used, for the wear is heavy. Suburban traffic is, as the name denotes, that found on city streets in their outer limits, and in the main thoroughfares of country towns. A rock of less hardness and toughness is required. Highway traffic is that found on the main country roads, for which a material of medium qualities should be used. Country road traffic exists on the less used roads in the least settled districts. A comparatively soft rock is needed in these localities. This division of traffic is purely arbitrary, yet of the greatest importance. At first thought it might appear that a rock well fitted for the heaviest traffic would surely be satisfactory for lighter travel. No greater mistake could be made. The two opposed forces: the wear on a road, and the hardness, toughness and binding power of the material used, giving resistance to wear, must actually balance each other to give the highest results in any given case. The road surface, composed of the necessary layer of fine material, must be renewed just as fast as it disappears. In other words, speaking broadly, as fast as the wind and water carry away the materials from the top of a road, just so fast should the under rock fragments grind down under travel to form new surfacing. The amount of work done by the wind and water should be reduced to a minimum by selecting a road metal with maximum binding quality. Then the other qualities of the stone must be fitted to the needs of the travel destined to be over it. If too small a supply of fine surface material, or "binder," be furnished, because of too light traffic for the particular stone used, the road "ravels," and the underlying rock fragments project, making the road rough as well as weak. If too much protecting surface be supplied, from too heavy traffic, the excess results in dust or mud. In a moist climate a thicker layer of surfacing is permissable than in a dry climate.

Having these few fundamental considerations in mind, it is possible to choose a road metal with greater chances of its success. The three main characteristics which must be considered first are hardness, toughness, and binding power. Hardness is the resistance of a rock or mineral to rubbing, as by grinding on an emery wheel, and to force applied to crush the stone. Toughness is the resistance to fracture by blows, as continually delivered upon a road by travel. The cementing power has been explained as due to slight chemical change in the rock. It is also due, in small part, to the mere presence of a little moisture. It is well known how firm wet sand is compared to dry. In all cases, a slight percentage of water in the mass of road material is necessary. There is, naturally, much diversity of opinion regarding the values of the various road materials. A rock suitable in all respects for one locality may easily prove a total failure in another. A stone much affected by frost should not be used in a cold region, nor will a brittle one give the best results in a dry climate. It appears to be the consensus of opinion that, all things considered those rocks called popularly "traps" are the best. These rocks are found typically as dykes, hence are intermediate in texture, and are largely diabase and diorite. They are among the toughest of the rocks, and usually have good binding power. The best varieties of these traps make satisfactory roads for urban traffic, but are too hard and tough for the lighter travel. The finer grained plutonic rocks probably come next in order of value, the more basic being the best as a rule, because of better cementing qualities. Granite is often frowned upon, yet some granites have given good results. The presence of hard, but brittle, quartz seems to be the chief objection, while micaceous granites, as well as all rocks containing mica, are unsatisfactory. However, given a binding power in a stone, any ordinary amount of free quartz is of real value, because it is not decomposed under ordinary conditions, and furnishes an unchanging base for the road. The volcanic rocks are of varying values. Basalt blocks are used for paving for city traffic, but for macadam their field is limited. Preference is given the crystalline rocks. Rhyolites, with sufficient binding power, have given excellent results in some localities. Andesites might also make good roads. The crystalline metamorphic rocks, the gneisses and schists have been used with good results. Of the atmospheric rocks, few seem to find favor. In the West, especially in California, such rocks have been largely used, with eminent success. In Golden Gate Park, San Francisco, a dark red chert has furnished material for the excellent roads, which are among the finest in the State. At other points around San Francisco bay, and in the interior valleys, where the climate is much like that of western Nevada, a metamorphic sandstone has made fine roads. Also, a dark basic diorite has been used for heavy traffic with satisfactory results. Limestone would seem on the face of the matter to be almost worthless as a road metal, yet some roads have been constructed of it in the east with great satisfaction. Some varieties are hygroscopic, that is, attract moisture from the air and might prove of service in a dry climate. Here in Nevada, and particularly near Reno, where the construction of stone roads will begin, there are several promising rocks. An immense supply of rhyolite containing considerable iron outcrops less than a mile north of Reno, and an abundance of a medium basic granite, much of it without mica, or with little, exists to the south and west. The latter rock, considering the traffic, might easily prove a success. Andesite and basalt, of unknown value, are also near by. The reddish andesite used in the Carnegie Library should make an excellent material for light travel. More rock of a similar nature is to be obtained in abundance at Huffaker's, on the line of the V. & T. railroad. The diorite of Mt. Davidson, and much of the unaltered rock extracted in the mines, should make a satisfactory rock for heavy traffic. Crystalline limestone, or marble, occurs in large amount in the eastern part of the state, as do many other desirable rocks for road metal. The possible value of lime rocks for road purposes in this dry climate has already been mentioned.

But in spite of these few general principles, and list of possible materials, there comes the one question "will such and such a stone be a success?" We are apparently confronted by the truth of the old maxim "the proof of the pudding is in the eating." Very fortunately, however, we are not driven to the necessity of actually constructing roads merely to test certain materials. The application of general principles to measurements of the various qualities of a rock not on a road building scale will tell almost everything needed in the way of information. Laboratories for the testing of road materials have been installed at several places in the United States. The two of particular value to Nevada are the laboratories at the University of California and at Washington, D. C., under the Department of Agriculture. In the latter case, any person may have a full test made of a rock for road construction free of charge, the only expense being that of freight charges on the railroad. Requests for blank forms and instructions should be addressed to the Road Materials Laboratory, Office of Road Inquiry, Department of Agriculture, Washington, D. C. Full tests are made, and the fitness of a stone for road material is given in detail. The laboratories at the University of Nevada are poorly equipped to make more than a few simple tests, for special apparatus is required. Considerable aid can and will be given to interested parties, however.

Although much in the way of principles underlying success in road construction have thus far been given, the most important condition of all has been assumed complied with, namely that the road be properly constructed. It lies beyond the scope of these few notes to enter upon the engineering side of road construction, and it is only urged upon the citizens of Nevada to inform themselves before commencing the building of stone roads. A perusal of the few references given at the end of the chapter will furnish all the facts necessary, and every voter should be acquainted with them. Macadam roads cost from $4,000 to $10,000 a mile, and an error in construction or judgment in selecting suitable material may mean great loss to a community.

There are two more materials which deserve serious consideration used in constructing roads. The first, and perhaps of little adaptability or value to most of Nevada, is vitrified paving brick, laid like ordinary basalt blocks in a road. Roads of this nature have proved very efficient in the esat, especially in the prairie States, and may prove of value elsewhere. A reference covering the subject is given. The second material is of the greatest value and adaptability to Nevada, with her dry climate. The unqualified and immense success of oil on roads, laying all dust and making a surface as smooth as asphaltum, recommends it as a possible boon to this section of the country, where water is scarce. When properly used, its success has always been immediate and great, and the consideration of its use is earnestly urged upon the citizens of this state. Its cost is nominal, and is partially compensated by the decrease in the cost of watering the streets treated. Some of the sandiest and dustiest roads in southern California have been made into perfect highways by its use, the result being much like a bituminized rock surface.

The following list of references will be found useful to all those interested. They may be obtained free of cost by applying to the Secretary of Agriculture, Washington, or at the Experiment Station at the University of Nevada.

(1.) "The Forces Which Operate to Destroy Roads, With Notes on Road Stones and Problems Therewith Connected." Circular No. 29. Office of Road Inquiry, U. S. Dept. of Agric.

(2.) "The Selection of Materials for Macadam Roads." Yearbook of Dept. of Agric., 1900.

(3.) "Historical and Technical Papers on Road Building in the United States." Bull. No. 17. Office of Road Inquiry.

(4.) "The Testing of Road Materials."' Bull. No. 79. Bureau of Chemistry, Dept. of Agric.

(5.) "Methods of Constructing Macadamized Roads." Circular No. 21. Office of Road Inquiry.

(6.) "Highway Repairing." Circular No. 24. Office of Road Inquiry.

(7.) "Brick Paving for Country Roads." Circular No. 25. Office of Road Inquiry.

(8.) "Earth Roads." Farmers' Bulletin No. 136. Dept. of Agric.

(9.) "The Use of Oil on Roads." Year book of Dept. of Agric., 1902.

(10.) "The Social, Commercial and Economic Phases of the Road Subject." Circular No. 34. Office of Road Inquiry.

(11.) "Going in Debt for Good Roads." Circular No. 26. Office of Road Inquiry.

(12.) "Wide Tires." Bull. No. 12. Office of Road Inquiry.

CHAPTER VI.

CONCLUSION.

There are a few points to be emphasized and a few explained before bringing this paper to a close. The real need of such publications, incomplete as they must necessarily be in a new and undeveloped State like Nevada, is surely apparent to all progressive citizens. The vast size of the unknown and undeveloped in the State is almost appalling when contrasted with what little is known. And the work of the future, the proper opening up of the State in all possible ways, depends largely upon the methods of its accomplishment. The haphazard stage has been passed, and we must build solidly and scientifically. The bonanzas have been exhausted from the great Comstock, and the future of that famous lode rests upon the scientific mode of attacking the problem now present: that of working immense bodies of low-grade ore at a profit. And with the agriculture of the State, that industry which heretofore lagged behind the rest, the great problems of irrigation are fundamentally connected. Every detail must be worked out scientifically, in accordance with law and order. Likewise with the building stones of Nevada. No order, and little real knowledge has governed the choice and use of materials in the past. No harm has been done, because the needs were few and simple. But with the growth of large towns and cities, new and great buildings will be required, and real scientific facts about the materials of construction available will be needed. And so with many other lines of human activity. We need not only to know, but to know in the right way; to have scientific knowledge, to understand law and truth. It is largely to aid in bringing about the acceptance of such considerations that this paper has been written.

Regarding the subject matter, a few words of explanation seem necessary. First, the rock classification may strike petrographers as rather behind the times. It is, and necessarily so. The tendency of modern petrographic thought ts toward the drawing of fine lines, and the classification of rocks in accordance with new ideas and conceptions. This is all necessary and right, but the unitiated have no use for such terms as "persalane," "dofemic," and the rest. A popular terminology will and must always be distinct from the petrographic, if such names are universally adopted by scientists. The main idea underlying the writing of the chapter on the classification of rocks is this: To convey some definite idea to the practical man regarding the meaning of the general names of rocks, with the characteristics appertaining thereto . Very unfortunately, it seems to the writer, that with the advent of more exact petrographic nomenclature must come more or less of a dual classification of rocks. The old terms are good and sufficient for all practical needs, and need no change for these purposes, no matter to what lengths the more exact terminology may go. Moreover, they cannot be changed, for obvious reasons, and this must not be forgotten by the scientist in his search after truth.

The chapter on the qualities of building stones is complete enough for the purposes of the present paper but will need more details for a larger report. The larger facts are, of course, given in full. Amplification of the methods of testing building materials is likewise needed when a final report is issued.

Regarding the rocks themselves, the list brings to light some important facts. It is to be seen that at present some amounts of stone are used, and that this use is daily increasing. Also it is stated with the awakening of the State to new and better times, a great increase in stone buildings will occur. But the cardinal point is this: So very little is known definitely about Nevada; the welfare of the State depends largely upon this knowledge of her resources, not only in the one small line of building stones, but in all the ways of human activity. This thought should not be lost sight of for an instant.

The chapter on road metal is included because it is believed to fill a real need for information. Reno must soon lay new streets to meet the demands of an increasing population, and it will not be long before some of the other large towns follow suit. And road construction, like many other engineering works, looks easy to the uninstructed. To the business man, mining appears to consist of digging a hole and taking out ore. Likewise to the same ordinary man of business, road making seems to consist merely of dumping a lot of rock on a road and smoothing it off a bit. Both ideas are greatly in error, and it is high time every good citizen knew something of the proper construction of roads. And it is to be remembered that it is not always, nor often, that the street which costs the least to construct is the cheapest.

Lastly, it is to be stated that all in his short paper has been written in the dawn of the light coming from the new day of prosperity for the State of Nevada, with her boundless wealth of material things just beginning to awaken due appreciation.

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THE VENTILATING-SYSTEM
AT THE
COMSTOCK MINES, NEVADA

BY

GEORGE J. YOUNG

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Ventilating-System at the Comstock Mines, Nevada.

BY GEORGE J. YOUNG,* RENO, NEV.

(Spokane Meeting, September, 1909.)

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I. INTRODUCTION.

DR. JOHN A. CHURCH, in his treatise on the Comstock Lode,[1] gave a full and clear account of the conditions of the mine during the period of greatest activity. The difficulties in the way of deep mining at that time were excessive water and high temperature. The drainage of the mines taxed the financial resources of the mining companies, and the high temperatures restricted the capacity of the miners for underground labor. In spite of these difficulties exploratory work was continued until the financial burden of removing the water became too great. The companies then restricted the work to the upper levels. The years 1883 to 1886 marked the period of cessation of deep mining.

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* Professor of Mining and Metallurgy, University of Nevada.

[1] *The Comstock Lode: Its Formation and History* (1879).

For 12 years thereafter mining was confined to the levels above the Sutro tunnel; and, while the question of drainage was more or less agitated, nothing of importance was done until the formation of the Comstock Pumping Association in 1898. Since that time successive levels have been drained until, at present, on the north-end mines, a depth of 700 ft. below the Sutro-tunnel level has been reached. Mining is now carried on in the Ophir mine from the 1,700- to the 2,200-ft. levels, and a winze is being sunk to make connection with the 2,300-ft. level (the 2,450 ft. of the C. & C. shaft).

In 1903 the Ward Shaft Association was formed to undertake the draining of the Central and Gold Hill group of mines, and at the present time a depth of 2,500 ft. has been reached in the Ward shaft. The situation at the Ward looks promising, and the 3,000-ft. level may be reached in the near future. It is proposed to establish a large pumping-station on this level, and then begin the opening of known ore-bodies and the prospecting for new ones.

The main factors which have contributed to the successful solution of the drainage problem are the Sutro tunnel, the use of the hydraulic elevator as a sinking-pump, the concentration of pumping-units, and cheap electrical power.

The question of high temperature and its control still remains as a minor but important problem. The temperatures encountered in the new workings are as great as those in the earlier periods. The Comstock was considered the hottest group of mines in the world, and I am not aware of similar conditions in any other mining-district. A water-temperature as high as 160° F. has been reported from the Ward shaft, and temperatures below the Sutro tunnel are very high in many instances.

The control of excessive underground temperatures is effected by proper ventilation, or by the provision and distribution of air-currents of sufficient volume. Upon the Comstock of late years considerable attention has been paid to ventilation, and underground conditions have been much improved.

The ventilation of metalliferous mines has received but little attention, and comparatively few data are available. The literature of coal-mining, on the other hand, is replete with data of mine-ventilation, the topic being one of considerable interest even at the present time. In coal-mines, ventilation has for its principal object the removal of explosive gases. To accomplish this, fans are generally employed to force into or exhaust from a mine large volumes of air. In metal-mining, while occurrences of gases are not infrequent, the volume of gas encountered is usually so small as to be unimportant, and it is generally non-explosive. In these cases the purpose of the ventilating-current is to supply pure air to the miners in the different working-places, and to remove the gaseous products of blasting. In but few instances has the ventilating-current to perform the additional function of cooling the mine-workings. In most metal-mines ventilating-currents are established by the use of two shafts, one an upcast, the other a down-cast. The natural elevation of the ground-temperature, due to increased depth, is relied upon to warm the air sufficiently to start an upward current. As depth is attained, the average temperature of the ascending current is raised and the ventilating-efficiency of an upcast shaft increased. Fans and air-pipes are used for the ventilation of pits, shafts, and dead-ends, but are seldom used for the general ventilation of a large mine. The Comstock mines furnish an excellent example of the use of natural ventilation for providing a current of sufficient volume partly to overcome abnormal conditions. That natural ventilation is insufficient and not controllable enough, is evidenced by the fact that at the present time one large fan is in operation and another is being erected. Ventilation by small fans is also very largely used to supplement the effect of the shafts. The purpose of this paper is to give a detailed account of the system of ventilation at present in use at the Comstock mines.

II. Temperatures.

In any system of natural ventilation, surface and underground temperatures play an important part.

1. *Surface-Temperatures and Conditions.*—Virginia City, Nev., does not possess a meteorological station, and consequently no records of the weather-conditions are available. However, the records of the government station at Reno, 18 miles NW., supply this deficiency. Virginia City has an altitude of between 6,000 and 6,500 ft., and Reno 4,553 ft., above sea-level.

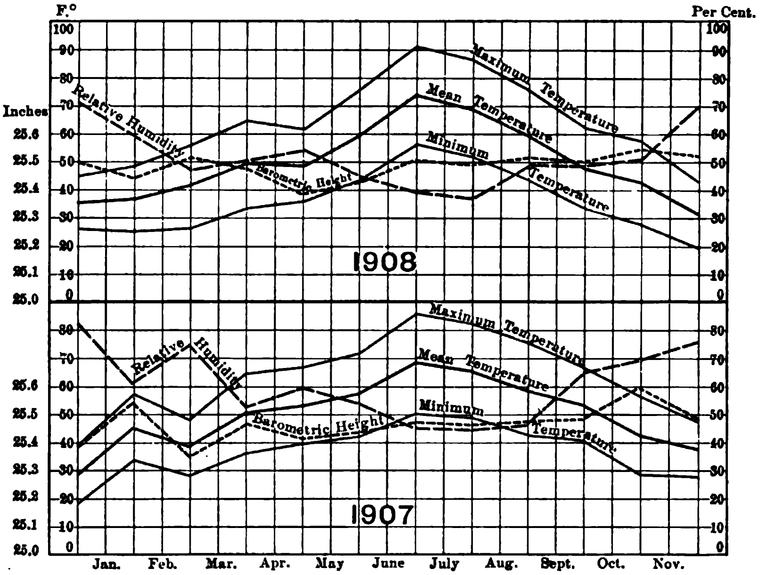

Fig. 1.—Curves of Maximum, Mean, and Minimum Temperatures, Relative Humidity, and Barometic Height, at Reno, Nev., in 1907 and 1908.

The difference in altitude would make some, but not a very great, difference in climatic conditions.

The maximum, mean, and minimum temperatures, the barometric height, and the average relative humidities for the years 1907 and 1908, are plotted in Fig. 1. It should be noted that the day-humidity is much less than the average 24-hr. humidity; for instance, in July, 1907, the average humidity of four days was 23; in August, the average of four days was 19; in September, the average of two days was 21.5; in October, the average of four days was 51; in November, the average of three days was 43; and in December, the average of four days was 64 per cent. The average day-humidity during the months of July, August, and September was 21; and for the months of October, November, and December it was 51 per cent. The air during the summer and fall months is characterized by a low day-humidity, and during the winter months the day-humidity is about normal. The average yearly temperature is about 50° F.

2. *Underground Temperatures.*—Becker[2] has given excellent data on the rock-temperatures prevailing at different points underground, and to this authority the reader is referred. Air-temperature only will be considered in this paper.

Records of air-temperature in the Ophir mine have been kept for some time, and from these records have been compiled Tables I., II., III., and IV.

TABLE I.—*Temperatures at Sutro-Tunnel Level.*

Date, 1908.	No. 1, South of Cross-cut to C & C. Shaft.	No. 2, South of Winze.	No. 3, Head of Winze.	No. 4, From Union Connection to Ophir Incline.
	Degrees F.	Degrees F.	Degrees F.	Degrees F.
June 4.......	85	102	104	100
June 5	90	102	102	100
June 6.......	87	100	104	98
June 8.......	90	100	100	90
June 10.......	92	100	104	.....
June 11.......	94	100	.....	.....
June 15.......	94	98	.....	98
June 24.......	96	.....	.....	.....
July 2.......	96	102	102	96
July 8.......	96	100	.....	.....
July 16.......	97	102	104	97
July 17.......	98	102	105	96

Table I. shows the temperatures measured in the north lateral of the Sutro tunnel during June and July, 1908. The hottest months are July and August, during which the conditions in the main Sutro tunnel in the vicinity of the Combination shaft are particularly trying. No. 1 station in the north lateral (about 500 ft. south of the connection to the C. & C. shaft) shows an average temperature of 91° F. for June and 96.7° for July. Only a feeble air-current was moving towards the Sutro tunnel at this station. At No. 2 station, between the C. & C. shaft connection and the "hot winze," the air was practically dead, and in June the average was 100.3°; for July it was 101.6°. On July 17, I measured a temperature of 102° at this point. No. 3 station, at the head of the "hot winze," delivering hot air from the workings of the Ophir mine below this level, gave an average June temperature of 102.8°, and for July, 103.3°. No. 4 station, at the connection with the Union shaft, showed an average temperature of 95.2° for June and 96.3° for July. The lowering of the temperature at No. 4 station was due to the cool air from the Union shaft leaking through a canvas curtain and joining the hot air at both the north lateral and the connection to the Union shaft. At stations Nos. 3 and 4 the temperature was measured in a swiftly-moving air-current.

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[2] Geology of the Comstock Lode and the Washoe District, *Monograph III.*, *U. S. Geological Survey*, pp. 228 to 265 (1882).

In the Sutro tunnel, south lateral, no temperature-records were available, but observations made by me showed a temperature of 108.9° in the vicinity of the Julia shaft, Dec. 13, 1908; in the Ward shaft connection, 101.1°; at the junction of the Ward shaft connection and the south lateral, 86°; at the connection of the Sutro tunnel and south lateral, 100°; west of the Combination partition, 94.6°, and east of the partition, 93.7°. A temperature has been noted[3] of 105° for Apr. 15, 1905, in the Sutro tunnel, east of the Combination partition, and during the months of July and August, 1908, this temperature is reported to have prevailed.

The Sutro tunnel is an incast and, as a consequence, the temperatures vary from a minimum at the portal to a maximum at the Combination partition. This variation was measured, and the results are shown in Table II. The tabulated results are plotted in Fig. 2.

An air-temperature of 46° was raised to 95° in passing a distance of 18,000 ft. The air-temperature in the Sutro tunnel varies with the temperature of the outside air, the temperature of the water passing through, and the rock-temperature. The most important factor is the temperature of the water pumped from the C. & C. and the Ward shafts. This water is passed through both the north and south laterals in 24-in. wooden-stave pipes, and at a point 1,000 ft. east of the Combination partition (approximately 18,000 ft. from the portal) the pipe terminates

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[3] Leon M. Hall and Frederic W. Bishop, *Report to the Comstock Pumping Association* (May 25, 1908).

TABLE II.—*Variations of Temperature in Sutro Tunnel.*

Date.	Distance from Portal.	Temperature of Water.	Temperature of Air.	Relative Humidity.	Notes.
	Feet.	Deg. F.	Deg. F.	Per Cent.	
Nov. 22, 1908.	Combination partition.	......	94.5	98.5	
Nov. 22, 1908.	18,000	......	94.4	98.2	Near Combination partition.
Nov. 22, 1908.	17,000	95.0	95.0	97.2	End of wood pipe.
Nov. 22, 1908.	13,000	......	95.0	93.7	
Nov. 22, 1908.	10,000	93.7	91.9	98.0	Prospect switch.
Nov. 22, 1908.	8,000	92.8	85.2	92	
Nov. 22, 1908.	6,800	90.7	73.0	83	Beginning of 30-in. pipe.
Nov. 22, 1908.	5,200	......	71.6	74	
Nov. 22, 1908.	0	......	46.0	59	
Dec. 13, 1908.	E. of Combination partition.	......	93.74	96.4	
Dec. 13, 1908.	16,400	92.5	93.2	100	
Dec. 13, 1908.	15,000	94.1	93.56	97.2	

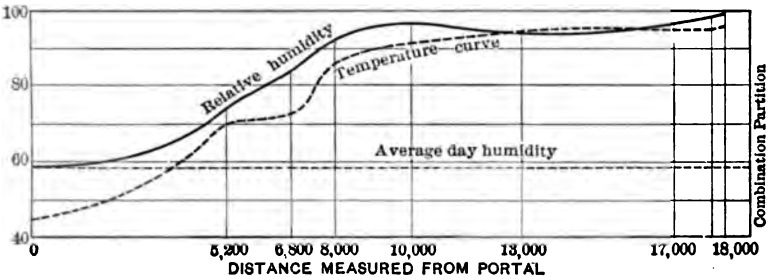

FIG. 2.—CURVES SHOWING TEMPERATURE AND RELATIVE HUMIDITY VARIATION IN THE SUTRO TUNNEL.

and the water flows out, occupying about two-thirds and in some cases the full width of the tunnel. From the portal a 30-in. stave pipe has been constructed a distance of 7,000 ft., and between this point and the former, or a distance of 11,000 ft., the air flows over the surface of the water. This exposure not only heats the air but also saturates it with water-vapor. The close coincidence between the air-temperature and the water-temperature should be noted.

The high temperature in the south lateral near the Julia shaft is due to rock-temperature more than to water, since in the south lateral the water is carried in a wooden pipe. The temperature-measurements in the north and south laterals are shown in Table III.

TABLE III.—*Temperature-Measurements in North and South Laterals of Sutro Tunnel.*

Date.	Distance.	Temperature of Water.	Temperature of Air.	Relative Humidity.	Notes.
		Deg. F.	Deg. F.	Per Cent.	
Dec. 13, 1908.	Surface, Ward shaft......	......	40.1	39.6	7.45 a.m.
Dec. 13, 1908.	1,600-level station.........	......	88.7	65.5	
Dec. 13, 1908.	Half to south lateral......	......	101.1	63.5	
Dec. 13, 1908.	Junction south lateral and Ward connection.	......	87.8	80.4	
Dec. 13, 1908.	South lateral south from charge station.	......	86	84.6	
Dec. 13, 1908.	2,300 ft. from tunnel......	......	96.8	64.4	
Dec. 13, 1908.	1,550 ft. from tunnel......	......	105.8	54.4	
Dec. 13, 1908.	400 ft. from tunnel.........	......	108.86	55.9	
Dec. 13, 1908.	100 ft. from tunnel.........	......	104.0	63.8	
Dec. 13, 1908.	Sutro tunnel at junction of south lateral.	.....	100	73.7	
Dec. 13, 1908.	Sutro tunnel 100 ft. west of north lateral.	......	87.8	91.4	
Dec. 13, 1908.	75 ft. west of Combination partition..........	......	94.6	83.9	
Oct. 11, 1908.	Outlet of air-pipe near winze, north lateral.	......	97.0	46.5	
Oct. 11, 1908.	Cross-cut to C. & C. shaft.....................	95.9	93.2	95.0	
Oct. 11, 1908.	Just before reaching Mint shaft..............	......	91.4	95.0	
Oct. 11, 1908.	Junction of Sutro tunnel and N. lateral....	......	90.9	94.0	

3. *Water-Temperatures in Sutro Tunnel.*—Opportunities for measuring the water-temperature are few and far between. On Oct. 11, 1908, the water discharged from the C. & C. shaft into the tunnel gave a temperature of 95.9° F.; on Dec. 12 the water from the Ward shaft, close to the Ward, gave a temperature of 141.8°. On the same day, at a point 15,000 ft. distant from the Sutro-tunnel portal, the water-temperature measured 94.1°. The water-flow from the C. & C. shaft amounts to from 4,000 to 4,500 gal., and from the Ward, from 600 to 800 gal. per min. In addition, all the water from the ground above the Sutro tunnel drains into the laterals and discharges into the Sutro tunnel. The average temperature of the water flowing into the Sutro tunnel at the Combination partition is between 94° and 95°. Miners say that sometimes this temperature is exceeded.

4. *Temperatures of Mine-Workings.*—The temperatures in the Ophir workings have been observed for some time, and from

TABLE IV.—*Temperature-Measurements in Different Parts of the Ophir Mine.*

Date, 1907.	2,250 Cross-cut Station.	2,200 Snow-sheds.	2,200 Fan.	2,100 Ophir.	2,100 N. Stopes.	2,200 Station.	2,200 Raise.
	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.
July 13	75	104	98	98	98	100	111
July 16	68	104	97	98	97	98	110
July 22	78	104	97	97	98	100	111
July 29	72	105	98	98	98	100	110
Aug. 7	72	110	98	98	98	99	111
Aug. 12	68	106	98	98	97	102	111
Aug. 20	66	108	97	98	97	105	113
Aug. 30	69	109	98	98	96	105	112
Sept. 12	66	104	97	98	97	101	112
Sept. 26	68	102	97	96	96	100	111
Oct. 3	62	104	96	97	98	100	110
Oct. 14	70	105	99	98	100	102	112
Oct. 24	64	103	98	101	102	102	110
Oct. 30	62	101	97	100	102	102	109
Nov. 9	58	97	94	97	100	101	110
Nov. 20	54	96	92	96	100	98	108
Nov. 25	55	100	87	95	100	98	108
Dec. 2	57	102	91	97	100	98	108
Dec. 9	57	109	92	99	100	99	109
Dec. 21	56	107	91	96	100	101	109
Dec. 26	57	109	92	96	100	101	108
Jan. 1, 1908	55	106	90	95	100	100	108
Jan. 15, 1908	60	107	91	95	100	100	108
Feb. 1, 1908	54	107	89	94	100	100	108
Feb. 18, 1908	56	112	93	91	101	102	108
Mar. 5, 1908	56	105	92	94	100	102	108
Mar. 31, 1908	57	108	93	96	100	104	108

TABLE V.—*Temperature-Readings in Different Parts of Ophir Mine and on Different Dates.*

Date, 1908.	2,250 Cross-cut Station.	2,250 Drift.	2,350 Drift.	2,100 N. Drift.	2,100 Stopes.	2,200 N. E. Drift.	2,200 Stopes.	2,200 Winze.
	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F
Apr. 27	63	106	130	104	103	104	105	106
May 20	64	112	112	101	102	101	104	103
May 23	64	114	129	101	102	101	104	102
May 28	65	112	128	100	101	100	102	102
June 1	65	112	126	100	101	101	103	101
June 5	62	110	127	100	101	99	101	101
June 6	62	108	126	100	101	99	101	100
July 20	74	100	102	101	104	104	105	102
July 23	75	100	101	101	102	100	102	100
July 25	75	104	104	102	103	101	102	100
July 30	77	105	110	102	102	105	103	100
July 31	76	101	110	102	105	104	104	101
Aug. 1	78	102	112	102	103	104	104	102
Aug. 3	76	100	110	101	103	104	104	102
Aug. 4	75	106	112	101	104	104	104	101
Aug. 5	74	100	112	101	102	102	102	101
Aug. 3, 6, 7	72	100	112	103	102	102	102	102

the daily reports Tables IV. and V. have been compiled. Only a few readings were tabulated, since but very little variation in the temperature takes place from day to day.

From Tables IV. and V. the following averages have been calculated for workings below the Sutro tunnel:

Working-Place.	Average from all Tables.	Average Maximum from all Tables.	Average Minimum from all Tables.
	Degrees F.	Degrees F.	Degrees F.
2,250 station, C. & C.	67	73.3	62.7
2,200 station, Ophir winze	101.2	102.1	100.6
2,150 drift	99.2	101.6	95.3
2,250 drift	105.6	110.5	101.8
2,350 drift	116.9	125.4	108.5
2,100 stopes	101.2	103.0	99.0
2,200 stopes	103.0	103.2	·102.8
2,200 raise	109.7	109.7	......

The temperatures given for the 2,250 and other stations of the C. & C. show the temperatures of the incoming air-currents on the different levels. The measurements in the drifts give the temperatures after the air has been heated to a maximum by contact with the walls of the drifts. A particularly hot zone was passed through by the 2,350 drift close to the 2,350 station of the C. & C. Before connection was made with the Ophir winze, the temperatures were so excessive as to cause the miners much suffering. As soon as a connection was made the temperature dropped about 15°. A progressive increase in temperature with depth is to be noted in the case of the drifts. Few measurements were made at different elevations in the stopes, but the air-current rises in temperature as it ascends in the stope. Confined mine-workings, such as drifts and raises, were usually observed to be the hottest workings, especially where no air-connections exist. Large mine-openings, such as stopes, are usually cooler.

III. The Ventilating-System in General.

A ventilating-current on the Comstock must provide pure air for the miners and a sufficient volume to temper the heat of the underground workings; it must also remove the steam and the gaseous products of blasting. A ventilating-current of sufficient volume to cool the workings enough to be noticeable would meet all the other requirements. The general and considerable elevation of temperature along the lode makes it possible to secure air-currents of some volume and velocity by natural ventilation alone. With the exception of the Ward shaft, all of the ventilation is effected by upcast shafts, supplemented by small fans for local distribution of the air in drifts, raises, stopes, and winzes. Three shafts, the Ophir, the Combination, and the Belcher, are used as upcasts; six shafts, the Union, the C. & C., the Mint, the old Yellow Jacket, the Overman, and the Alta, are used as down-casts. The Ward shaft is divided by a brattice ; and one compartment (the pump) is used as an upcast, the other two compartments, in which the hoisting is done, serving as a down-cast. A fan is attached to the upcast compartment and exhausts the air.

1. *Ophir Upcast.*—This shaft takes the air from the workings of the Ophir mine, the down-cast air coming principally from the C. & C. shaft. The upcast air is taken from a winze in the north lateral and by a cross-cut to the Ophir incline, and thence to the foot of the Ophir shaft. At the foot of the Ophir shaft a south drift takes air from old stopes and workings of the Ophir mine, and an east cross-cut connects with the Union shaft and takes air from that shaft.

2. *Combination Upcast.*—This shaft draws air from the Sutro tunnel, both east and west of the Combination partition, which is so placed as to split the connection from the Combination shaft to the Sutro tunnel. The down-cast air comes from the Union, Mint, and Alta shafts. The air from the Union crosses the current from the Ophir through a 20-in. galvanized-iron pipe, two wooden partitions keeping the currents from mixing. The air from the Mint shaft is taken through three lines of 15-in. air-pipe, assisted by fans, to the Gould and Curry, the Savage, the Chollar, and the Hale and Norcross workings. It is then returned through the north and south laterals to the Sutro tunnel, and thence to the Combination shaft. The air from the Alta passes through a long connection and into the south lateral near the connection to the Ward shaft. The air east of the Combination partition comes from the Sutro-tunnel portal.

3. *Belcher Upcast.*—This shaft ventilates the Yellow Jacket, the Overman, and the Caledonia mines, and draws air for this purpose down the old Yellow Jacket and the Overman shaft.

The total amount of upcast air from the three shafts and the

Ward measures 235,835 cu. ft. per min., and the amount of down-cast air measures 216,687 cu. ft. per min. The discrepancy between the two amounts is due to the difficulty of making accurate measurement, of rise in temperature, leakage, variation in the velocity of the air-current at different times, and the accession of water-vapor and gases from the mine-workings. The distribution of the air between the shafts is shown by Table VI.

TABLE VI.—*Distribution of Air in Upcasts, Down-Casts, and the Sutro Tunnel.*

Shaft.	Number of Compartments.	Area.	Quantity.	Temperature at Collar.	Temperature at Level.	Connecting Level at Bottom.	
		Sq. Ft.	Cu. Ft. per Min.	Deg. F.	Deg. F.		
Combination......	4	129	51,651	87.6	95.2	1,600	Yellow Jacket
Ophir...............	4	94	58,454	88.9	98.8	1,600	
Belcher.............	3	60	31,706	73.9	87.3	1,100	
Ward................	1	33	94,024	67.5	104	2,475	
Total upcast air..	12	316	235,835				
C. & C..............	3	77.3	28,941				
Union...............	4	126	13,814				
Yellow Jacket...	3	64.2	10,665				
Alta..................	2	43.3	13,364				
Mint..................	1½	30	7,500				
Overman on 900-ft. level..	3	60	5,981				
Unaccounted for in Belcher	....	....	15,060				
Sutro tunnel......	1	63	27,339				
Ward shaft........	2	55	94,024				
Total down-cast air.......	19½	518.8	216,687				

From Table VI. the average velocity in feet per minute has been calculated as follows:

	Cu. Ft. Per Min.
Whole upcast area, ...	746.3
Whole down-cast area, ...	417.6
Whole upcast area, excluding Ward shaft, ...	501.1
Whole down-cast area, excluding Ward shaft, ...	264.4

An interesting comparison with past conditions is afforded by the data given by Church.[4] Table VII. is quoted from his treatise.

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[4] *The Comstock Lode: Its Formation and History*, p. 18 (1879).

TABLE VII.—*Distribution of Upcast Air, July* 2, 1877.

Shaft.	Quantity.	Temperature of Upcast at Top of Shaft.
	Cu. Ft. per Min.	Degrees F.
Utah	4,000	.....
Sierra Nevada	7,700	76
C. & C.	21,600	84
Con. Virginia	48,750	89
Gould and Curry	12,000	.....
Savage	58,500	100
Chollar-Potosi	18,000	77
Bullion	10,080	89.5
Imperial Consolidated	28,800	95
Belcher	52,200	89
Overman	27,000	93
Total upcast air	288,630	Aver. temp.....88.05

Six shafts served as down-casts, but were not named. Church estimates the above quantity of air as a minimum, and states that probably 300,000 cu. ft. represents the average amount of upcast air, and 10,000 cu. ft. per min. as the quantity of air due to the air-compressors in use. The outside temperature for the day upon which the measurements were made is given as 73° F.

The average amount of air per upcast, from Table VII., is 26,240 cu. ft. per min., and temperatures at the top of the shaft average 88.05°. Excluding the Ward shaft, Table VI. shows an average of 47,270 cu. ft. per min. per shaft, and a top-temperature average of 83.4°. The figures indicate a somewhat greater effect for the upcast shafts at the present time than in the past. The lower average temperature shows the effect of the restricted workings. The fewer upcast shafts and the restricted workings of the present time would indicate, on the whole, a greater resistance to the movement of the air than at the time Church made his studies. The greater effectiveness of the present upcast shafts could be explained by the more liberal use of small fans. No detailed data are available concerning the use of small fans during the early periods of the Comstock. Of the shafts mentioned by Church, only the C. & C., Belcher, and Overman are open, and of these the C. & C. and Overman are used as down-casts, while the Belcher is an upcast at the present time.

Fig. 3 shows the relation of the underground workings, the principal upcast and down-cast shafts.

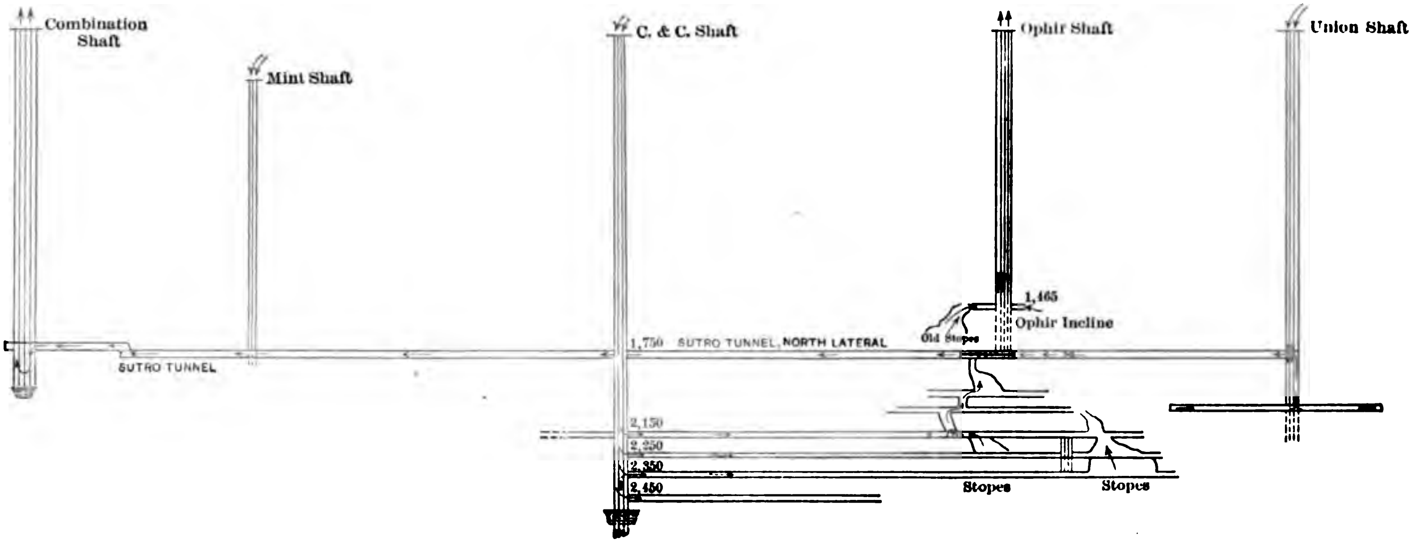

FIG. 3.—LONGITUDINAL SECTION, SHOWING WORKINGS AND SHAFTS OF NORTH-END MINES.

IV. THE VENTILATING-SYSTEM IN DETAIL.

1. *Union Shaft.*—The down-cast air is taken to the 2,000-ft. level, and thence by means of a 15-in. air-pipe to a fan 600 ft. distant in the east cross-cut. It is then forced to the face of the NW. cross-cut, and also to the face of the south drift, distances respectively of 500 and 1,000 ft. The discharges are respectively 1,042 and 796 cu. ft. per min. The combined discharge is 1,838 cu. ft. per min. With an inflow at the Union shaft of 4,287 cu. ft. per min., the delivery is 42.9 per cent. of inflow. The air returns through the east cross-cut to the shaft and then passes up through the pump-compartment, which is bratticed off, to the Sutro-tunnel level, and then through a long connection to the south lateral and also to the connection leading to the Ophir shaft. The north lateral takes 4,086 cu. ft. per min., and the remainder, 9,728 cu. ft. per min., finds its way into the Ophir upcast. The average temperature on the 2,000-ft. level is 98.3° F., and on the Sutro-tunnel level it is 76.3°. This is due to the fact that a comparatively large proportion of the down-cast air leaks past the air-pipe on the 2,000-ft. level and goes up the pump-compartment, cooling the air coming from the Union workings. The portion of air passing to the Combination shaft traverses 12,061 ft. from surface to surface; the portion passing up the Ophir moves 7,680 ft. Fig. 4 shows in plan the distribution of the air on the Sutro-tunnel level, and Table VIII. gives the measurements made on the same level.

2. *The Ophir Mine.*—The down-cast air in the C. & C. shaft splits into four parts—one split on the 2,150-ft. level, an air-current of 7,024 cu. ft. per min.; one on the 2,250-ft. level, an air-current of 14,521; one on the 2,350-ft. level, of 11,667, and one on the 2,350-ft. level, which was not measured.

On the 2,150-ft. level the air is taken through the drift to a point 860 ft. from the shaft, then picked up by a fan and forced to the Ophir winze and down through that connection to the stopes upon the 2,200-ft. level of the Ophir. The fan takes 5,389 cu. ft. per min., and the difference, 1,635 cu. ft., leaks past a canvas curtain and joins the upcast air.

On the 2,250-ft. level part of the air is taken by a fan at the station and forced down to the 2,350-ft. level to ventilate the

TABLE VIII.—*Measurements of Air, Temperatures, and Relative Humidities at the Sutro-Tunnel Level.*

Section.	Date, 1908.	Velocity.	Area Section.	Quantity.	Temperature.	Relative Humidity.	Notes.
		Ft. per Min.	Sq. Ft.	Cu. Ft. per Min.	Deg. F.	Per Cent.	
F.	Dec. 28.	228	63	13,364	84.2	86.2	Air from Alta shaft.
F.	Dec. 13.	161	63	10,134	86.0	84.6	Air from Alta shaft.
G. & C.	Nov. 15.	1,159	1.23	1,426	65.2	71.0	To Gould and Curry through 15-in. pipe.
G. S.	Nov. 15.	904	2.66	2,404	65.2	71.0	To Savage through 15-in. pipe.
H. & N.	Nov. 15.	2,452	1.39	3,408	65.2	71.0	To Hale and Norcross through 15-in. pipe.
G. & C.	Dec. 28.	1,122	1.23	1,380	63.1	77.8	To Hale and Norcross through 15-in. pipe.
G. S.	Dec. 28.	886	2.66	2,357	63.1	77.8	To Hale and Norcross through 15-in. pipe.
H. & N.	Dec. 28.	2,706	1.39	3,761	63.1	77.8	To Hale and Norcross through 15-in. pipe.
T.	Dec. 13.	1,035	8.1	8,221	87.8	91.4	Through door.
Winze.	July 15.	980	20.0	19,600	107.6	100—	Mine air.
J.	July 16.	650	39.0	25,336	105.4	100—	Curtain at N. closed.
J.	July 16.	433	39.0	16,454	105.4	....	Curtain at N. open.
J.	July 17.	600	39.0	23,400	104	97	Curtain at N. closed.
J.	July 17.	329	39.0	12,831	104	....	Curtain at N. open.
J.	Oct. 11.	567	54.5	30,901	93.2	95	Partition at N.
J.	Dec. 12.	874	39.0	30,186	99.0	81.2	Partition at N.
J.	Dec. 29.	940	35.0	32,760	100.4	76.4	Partition at N.
K.	July 15.	1,060	29.7	31,482	101.3	100—	Curtain at N. closed.
K.	July 16.	1,108	29.7	32,907	100.4	100—	Curtain at N. closed.
K.	July 17.	730	35	25,550	98.6	97.9	Curtain at N. closed.
K.	July 17.	809	35	28,315	95.0	....	Curtain at N. open.
M.	July 16.	464	35	16,440	105.8	....	Air from old stopes.
M.	July 17.	330	35	11,550	104.9	....	Air from old stopes.
L.	July 16.	210	20	4,200	93.2	....	Air from Union shaft.
L.	July 17.	145	20	2,900	95.9	....	Air from Union shaft.
R.	July 15.	190	56	10,640	91.4	....	
R.	July 16.	190	35	6,650	87.8	....	Curtain closed at N.
R.	July 16.	376	35	13,160	87.8	....	Curtain open at N.
R.	July 17.	120	35	4,200	88	73.4	Curtain closed at N.
R.	July 17.	221	35	7,735	85.8	....	Curtain open at N.
R.	Dec. 12.	3,291	0.4	1,316	86.4	66.8	Air-pipe in partition.
N.	Dec. 12.	364	22.4	8,143	82.4	72.4	Curtain removed.
O.	Dec. 12.	278	14.72	4,086	82.4	72.4	Air going to I.
P.	Dec. 12.	109	31.00	3,379	82.4	72.4	
Q.	Dec. 12.	478	28.85	13,814	82.4	70.3	
H.	Oct. 11.	1,632	2.07	3,378	97	46.5	20-in. pipe.
H.	Dec. 29.	1,750	2.07	3,622	94	48.0	20-in. pipe.
I.	Oct. 11.	1,750	2.00	3,500	93.6	49.0	20-in. pipe.

east drift; the remainder, amounting to 14,521 cu. ft. per min., passes into the drift until it reaches a stope, where two fans pick it up, one forcing the air past the stope into the Consolidated Virginia workings, the other forcing the remaining air down through the Ophir winze to the 2,200-ft. level of the Ophir mine. The Consolidated Virginia fan (No. 3) takes 3,323 cu. ft. per min., while the Ophir fan (No. 2) takes 11,566 cu. ft. per min. Beyond the stope another fan (No. 1) takes air from the Ophir-winze station and forces it on to the stopes north of the Ophir winze. This air rises up through the stopes and event-

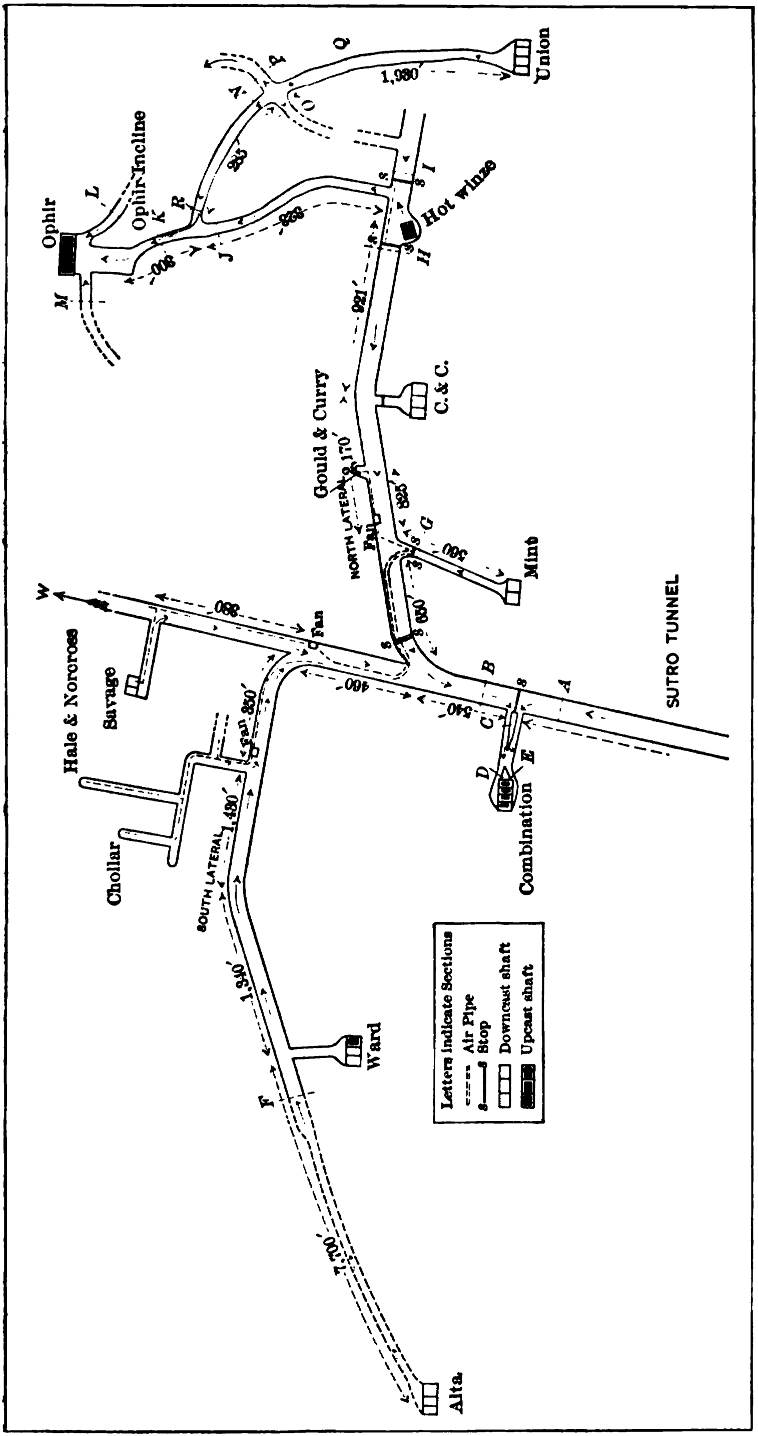

FIG. 4.—PLAN SHOWING DISTRIBUTION OF AIR ON SUTRO-TUNNEL LEVEL.

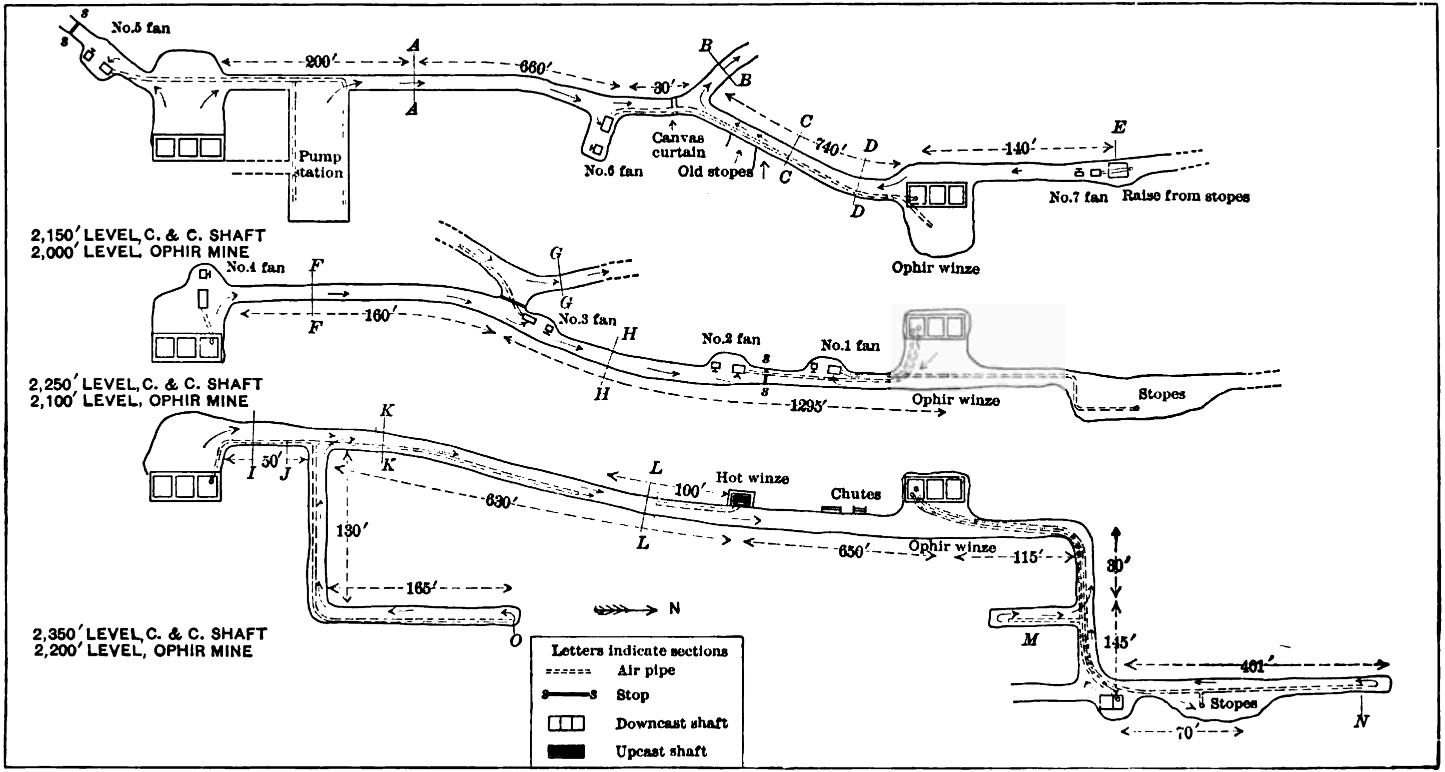

FIG. 5.—PLAN OF 2,000-, 2,100- AND 2,200-FT. LEVELS OF THE OPHIR MINE.

ually joins the air in the "hot winze" of the north lateral. The fan takes 3,791 cu. ft. per minute.

The air on the 2,350-ft. level passes through the main drift, while the air from the fan on the 2,250-ft. level passes into a cross-cut and a drift east of the main drift, returns, and joins the air passing through the main drift towards the Ophir winze. The high temperatures, noted previously, were taken in this drift before the connection was made. The average temperature before connection was 125.4°, and some months later the temperature measured 100.4°. The lowering in temperature was due to the increased volume of air and to the boarding-up (snow-shedding) of the sides and top of the drift, which very effectually shut off hot water, steam, and much of the heat radiated from the rock-surfaces.

The 2,450-ft. level is ventilated by a No. 8 cast-iron American blower. The air is taken through an inlet-pipe extending towards the south compartment of the shaft and forced to the working-face in the east cross-cut, returning through the cross-cut. The fan was not in operation at the time of my visit. On account of the danger of flooding this level the fan was driven by a compressed-air engine.

The total quantity of air in the three main splits amounts to 33,212 cu. ft. per min., and this compares closely to the 32,760 cu. ft. measured on the same day on the Sutro-tunnel level. Fig. 5 shows the plans of the three levels of the Ophir mine, with the sections at which velocity-measurements were made. The measurements are given in Table IX.

3. *Gould and Curry Mine.*—At the Sutro tunnel a west cross-cut has been started. This is ventilated by an air-pipe and fan which takes air from the Mint shaft. The inflowing air at the shaft measured 1,122 cu. ft. per min. (1,159 cu. ft., November 15). A 15-in. air-pipe takes this air to the fan, and from the fan an 11-in. pipe connects with the cross-cut, distant 189 ft. The air discharged measured 989 cu. ft., or 88.1 per cent. of the inflow. The fan was not in use.

4. *Savage Mine.*—An east cross-cut is being run in the Savage mine from a raise 75 ft. above the Sutro tunnel, which also receives air from the Mint shaft. A 15-in. air-pipe takes 2,404 cu. ft. per min. to a fan 1,110 ft. distant in the Sutro tunnel, and the fan discharges through a 15-in. pipe to the top of the

TABLE IX.—*Air-Measurements at Different Sections in Ophir Mine.*

Date, 1908.	Level.	Section.	Area.	Velocity.	Quantity.	Temperature.	Relative Humidity.	Notes.
			Sq.Ft.	Ft. per Min.	Cu. Ft. per Min.	Deg. F.	Per Cent.	
July 15.	2,000	A.	29.75	240	7,140	97.2	86.5	
Dec. 29.	2,000	A.	31.50	223	7,024	87.4	34.2	
July 15.	2,000	No. 6 fan.	1.77	2,766	4,896	....	......	Velocity low.
Dec. 29.	2,000	No. 6 fan.	1.77	3,045	5,389	98.6	37.5	Inlet of fan.
July 15.	2,000	B.	29.75	480	14,280	116.6	100—	Air to upraise to Sutro tunnel.
Dec. 29.	2,000	B.	28.22	620	14,396	108.1	86.7	Air to upraise to Sutro tunnel.
July 15.	2,000	C.	28.05	175	4,900	112.8	45.4	
Dec. 29.	2,000	C.	26.00	156	4,056	105.8	58.8	
Dec. 29.	2,000	D.	25.6	434	11,110	107.6	59.1	
July 15.	2,000	E.	20	225	3,375	100	98.5	
July 15.	2,100	F.	29.75	397	11,810	76.1	95.4	
Dec. 29.	2,100	F.	31.5	461	14,521	64.8	93.3	
July 15.	2,100	G.	26	320	8,320	96	89	
Dec. 29.	2,100	No. 3 fan.	2.82	1,182	3,323	....	......	
July 15.	2,100	H.	29.75	280	8,330	82.4	79.8	
Dec. 29.	2,100	H.	30.9	284	8,776	90.1	55.3	
Dec. 29.	2,100	No. 2 fan.	7.01	1,650	11,566	90.1	55.3	
Dec. 29.	2,100	No. 1 fan.	1.67	2,270	3,791	100.4	49.7	Temperature taken at Ophir-winze station.
July 15.	2,200	I.	28.25	220	6,140	89.6	96.4	Connection made.
July 15.	2,200	J.	1.22	3,492	4,160	82.4	......	End of 15-in. air-pipe; air from No. 4 fan.
Dec. 29.	2,200	K.	28.25	418	11,667	84.2	88.4	
Dec. 29.	2,200	L.	....	....	....	98.6	98.8	End of snow-sheds.
Dec. 29.	2,200	Hot winze	....	....	....	102.7	98.8	
Dec. 29.	2,200	....	....	......	....	104	98.8	50 ft. south of Ophir winze
Dec. 29.	2,200	Ophir winze.	....	....	....	100.4	45.8	
Dec. 29.	2,200	O.	1	1,996	1,996	89.6	40.6	Air from pipe, No. 4 fan.
Dec. 29.	2,200	M.	1.22	606	739	102.2	48.5	Air from pipe, No. 1 fan.
Dec. 29.	2,200	N.	1.11	490	544	104.5	86.5	Air from pipe, No. 1 fan.
Dec. 29.	2,200	....	....	....	....	98.6	72.6	Stopes between 2,100- and 2,200-ft. levels.

raise and then by an 11-in. pipe to the working-face, 180 ft. distant from the top of the raise. The discharge measures 894 cu. ft. per min., or 37.1 per cent. of the inflow. The section of 11-in. pipe caused the most leakage. The fan was in operation at the time.

5. *Hale and Norcross Mine.*—The Hale and Norcross receives air from the Mint shaft. A 15-in. air-pipe leads to the H. & N. connection in the south lateral, 1,460 ft., and from this point a fan takes the air and forces it to the H. & N. and Chollar cross-cuts, distant 325 ft.; 11-in. branch-pipes take the air to the working-faces, 190 ft. to the H. & N. and 122 ft. to the Chollar. The H. & N. discharge measures 941 and the Chollar 934 cu. ft. per min. The combined discharge measures 1,875 and the inflow at the Mint 3,761 cu. ft. per min. The discharge is 49.8 per cent. of inflow. The measurements of both the Chollar and the H. & N. are given in Tables X. and XI. and Fig. 6.

TABLE X.—*Air-Measurements in Hale and Norcross and Chollar Mines.*

Point.	Velocity.	Area.	Quantity.	Temperature.	Relative Humidity.	Notes.
	Ft. per Min.	Sq. Ft.	Cu. Ft. per Min.	Deg. F.	Per Cent.	
Mint Shaft.	2,452	1.39	3,408	65.2	71	Nov. 15, 1908. Air going into H. & N. air-pipe.
Mint Shaft.	2,706	1.39	3,761	63.1	77.8	Dec. 28, 1908.
B.	1,416	0.66	934	104.5	23.8	Nov. 15, discharge of 11-in. pipe.
B.	....	....	....	105.1	61.4	Dec. 28, discharge at J, 78 ft. from B.
J.	1,093	0.66	721	106.2	22.0	Dec. 28, discharge of 11-in. pipe.
C.	....	....	....	97.5	69.0	Nov. 15.
C.	....	....	....	104.0	51.2	Dec. 28.
E.	1,426	0.66	941	106.1	21.8	Nov. 15, discharge of 11-in. pipe.
E.	....	....	....	107.6	32.2	Face of drift 12 ft. from end of pipe, Nov. 15.
E.	1,043	0.66	688	109.4	20.0	Discharge of 11-in. pipe, Dec. 28.
E.	....	....	....	109.6	29.8	Face of drift 25 ft. from end of pipe, Dec. 28.
D.	....	....	....	95.5	66.2	Nov. 15.
F.	....	....	108	81.7	51.4	Leakage, 15-in. damper; cooling bench, Nov. 15.
F.	2,410	1.39	3,350	104.0	24.8	Damper on split closed; F open, Dec. 28.
F.	1,360	1.39	1,890	104.0	24.8	Both dampers open, Dec. 28.
F.	8	1.39	....	104.0	24.8	Damper at F closed, Dec. 28.
G.	9	....	....	98.1	64.4	Nov. 15.
G.	....	....	....	100.4	62.5	Dec. 28.
H.	....	....	....	105.8	66.6	Nov. 15.
H.	....	....	....	108.1	62.7	Dec. 28.
A.	....	....	....	105.5	58.5	Nov. 15.
A.	....	....	....	104.0	63.8	Dec. 13.
H.	....	....	....	108.86	55.9	Dec. 13.

TABLE XI.—*Inflow and Discharge of Air at Hale and Norcross and Chollar Mines.*

Date, 1908.	Inflow.	Discharge.	Air Lost.	Quantity Delivered.	Distance.
	Cu. Ft. per Min.	Cu. Ft. per Min.	Cu. Ft. per Min.	Per Cent.	Ft.
Nov. 15......	3,408	1,983	1,425	58	2,137
Dec. 28.......	3,761	1,409	2,352	37.4	2,155
Dec. 28.......	3,761	3,350	411	89	1,730

6. *Sutro Tunnel.*—The Sutro tunnel is an incast air-way and is the longest air-way on the Comstock. A plan of the tunnel at the Combination partition is shown in Fig. 7. The air enters at the portal and passes to the Combination partition,

a distance of 18,700 ft.; then through the connection to the Combination shaft, a distance of 400 ft., and then to the surface, a distance of 1,600 ft. vertically. The total distance is 20,700 ft. This Combination shaft also serves to draw air from the workings west of the Combination partition. The average quantity of air from the east is 27,339 cu. ft. per min. (average of four observations at different times); from the west it is 29,961 cu. ft. per min. (average of four observations at different times); and the total average passing to the Combination from both directions measures 57,300 cu. ft. per min. The observations made at the Combination partition are tabulated in Table XII.

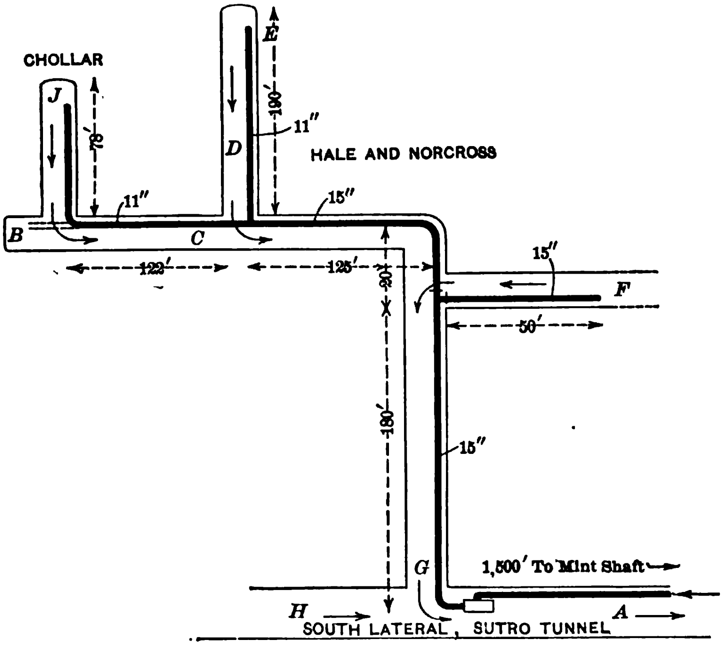

FIG. 6.—PLAN OF CHOLLAR AND HALE AND NORCROSS WORKINGS.

An interesting comparison is afforded by a measurement made in the Sutro tunnel, Mar. 7, 1909. The Sutro tunnel just west of the Combination partition was completely blocked by a cave, and the Combination shaft drew air only from the east side. The quantity of air measured 30,124 cu. ft. per min.; temperature, 89.6° F.; relative humidity, 100 per cent. The temperature at the foot of the shaft measured 92.3°; relative

TABLE XII.—*Observations on Air-Currents at the Combination Partition.*

Date, 1906.	Section.	Velocity.	Area.	Quantity.	Temperature.	Relative Humidity.	Barometer.	Time.
		Ft. per Min.	Sq. Ft.	Cu. Ft. per Min.	Deg. F.	Per Cent.	In.	
Oct. 11..............	D.	730	35.72	26,075	94.3	96	....	11.20 a.m.
Oct. 11..............	E.	850	27.58	23,443	95.4	95.4	....	11.20 a.m.
Oct. 11..............	C.	1,154	18.9	21,810	95.54	85.7	....	11.20 a.m.
Oct. 11..............	A.	492	48.5	23,813	97.52	93.0	....	11.20 a.m.
Nov. 15..............	A.	523	48.5	26,500	95.0	100	25.4	....
Nov. 22..............	A.	631	48.5	32,181	94.5	98.4	25.15	9.00 a.m.
Dec. 13..............	A.	604	48.5	30,200	93.7	96.4	25.10	10.00 a.m.
Dec. 28..............	A.	480	48.5	24,000	94.1	96.4	25.35	11.00 a.m.
Nov. 15..............	B.	627	46.3	29,307	95.5	85	25.4	
Nov. 22..............	B.	732	46.3	33,891	95.2	83.9	25.1	9.00 a.m.
Dec. 13..............	B.	628	46.3	29,076	94.64	83.9	25.15	11.10 a.m.
Dec. 28..............	B.	594	46.3	27,572	94.50	83	25.39	11.00 a.m.

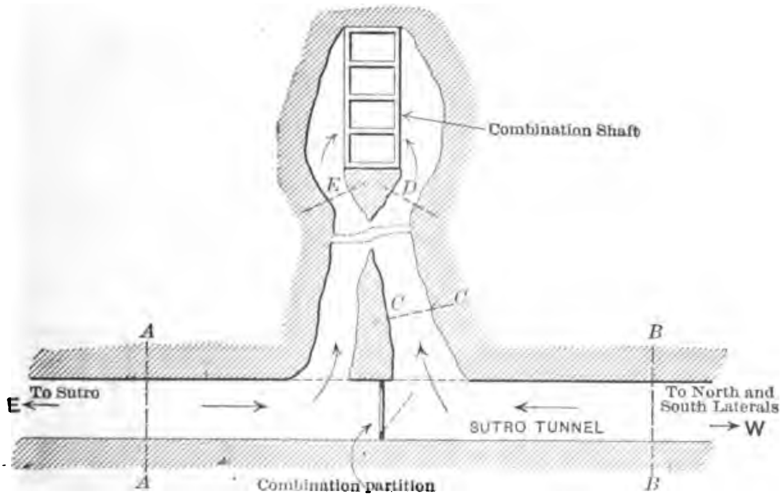

FIG. 7—PLAN OF SUTRO TUNNEL AT COMBINATION PARTITION.

humidity, 96.5 per cent.; barometer, 25.15 in. A measurement was taken on the same date, within 2 hr. of the measurement in the tunnel, at the collar of the Combination shaft, and 32,719 cu. ft. per min. at a temperature of 72°; relative humidity, 100 per cent.; and barometric height, 23.85 in., was the result. These figures show a pronounced cooling-effect of the shaft with a smaller volume of air passing, and this would decrease the efficiency of the shaft as an upcast. Instead of obtaining a greater volume of air by turning the full effect of the upcast shaft upon the tunnel, only a small increase resulted. This is a direct result of the decreased efficiency of the shaft.

A recording-anemometer was placed in the Sutro tunnel close to the Combination partition, and three 24-hr. records taken of the east air. The observed velocities are tabulated in Table XIII., the average velocities in Table XIV., and the quantities of air in Table XV. The anemometer was placed in the position shown in Fig. 8. The ratio between the average velocity for the section and the velocity for the position was determined by measurements with the small anemometer. This ratio was found to be 1.12, and this figure was used in reducing the observed velocities. The area of the section is 48.5 sq. feet.

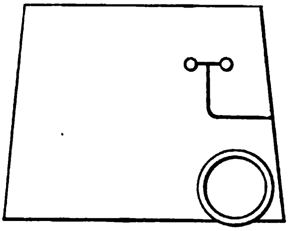

FIG. 8.—SECTION OF SUTRO TUNNEL EAST OF COMBINATION PARTITION, SHOWING POSITION OF ANEMOMETER.

TABLE XIII.—*Velocity-Readings.*

Time.	Nov. 21 to 22, 1908.	Nov. 22 to 23, 1908.	Nov. 23 to 24, 1908.	Time.	Nov. 21 to 22, 1908.	Nov. 22. to 23, 1908.	Nov. 23 to 24, 1908.
	Miles Per Hr.	Miles Per Hr.	Miles Per Hr.		Miles Per Hr.	Miles Per Hr.	Miles Per Hr.
12 to 1 p.m.	....	....	....	1 to 2 a.m.	5.00	4.70	5.60
1 to 2 p.m.	....	3.90	....	2 to 3 a.m.	5.00	4.80	5.50
2 to 3 p.m.	....	3.75	....	3 to 4 a.m.	4.20	4.62	5.90
3 to 4 p.m.	4.25	4.40	4.90	4 to 5 a.m.	4.34	4.75	5.50
4 to 5 p.m.	4.00	4.30	5.40	5 to 6 a.m.	3.90	5.13	5.50
5 to 6 p.m.	4.33	4.20	5.20	6 to 7 a.m.	4.16	4.80	5.40
6 to 7 p.m.	4.30	4.50	5.00	7 to 8 a.m.	4.55	4.80	5.74
7 to 8 p.m.	4.30	4.44	5.00	8 to 9 a.m.	4.62	5.00	5.45
8 to 9 p.m.	4.30	4.64	5.20	9 to 10 a.m.	4.60	4.80	5.40
9 to 10 p.m.	4.47	4.34	5.25	10 to 11 a.m.	4.26	4.20	5.30
10 to 11 p.m.	4.93	4.50	5.55	11 to 12 a.m.	4.50	4.10	5.30
11 to 12 p.m.	5.07	4.55	5.64	12 to 1 p.m.	4.25	4.20	4.60
12 to 1 a.m.	5.13	5.10	5.38	1 to 2 p.m.	....	4.00	....

TABLE XIV.—*Average Velocities.*

Date. Nov., 1908.	Average.		Maximum.		Minimum.		Time, Maximum.	Time, Minimum.
	Miles Per Hr.	Ft. Per Min.	Miles Per Hr.	Ft. Per Min.	Miles Per Hr.	Ft. Per Min.		
21 to 22.	4.98	438.3	5.75	505.2	4.37	384.4	12 to 1 a.m.	5 to 6 a.m.
22 to 23.	4.65	409.2	5.75	505.2	4.37	384.4	5 to 6 a.m.	1 to 2 a.m.
23 to 24.	5.99	527.1	6.61	581.3	5.16	453.4	3 to 4 a.m.	12 to 1 p.m.
Average...	5.21	458.5	6.04	530.6	4.63	407.4	....	....

The observed velocities have been plotted in Fig. 9.

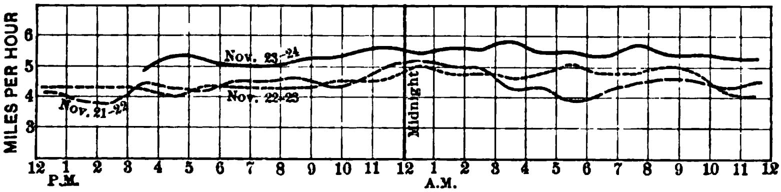

FIG. 9.—CURVES SHOWING RELATION BETWEEN VELOCITY AND TIME OF DAY.

TABLE XV.—*Air in Cubic Feet Per Minute.*

Date.	Average Quantity of Air.	Maximum Quantity of Air.	Minimum Quantity of Air.
	Cubic Feet.	Cubic Feet.	Cubic Feet.
Nov. 21 to 22....	21,257	24,502	18,859
Nov. 22 to 23....	19,846	24,502	18,859
Nov. 23 to 24....	25,564	28,193	21,990
Average...........	22,222	25,732	19,903

The average quantity, as shown in Table XV., and all the velocities, with the exception of one, are lower than the average velocity obtained from the readings in Table XII. Maximum and minimum velocities do not occur at any particular time. The wavy character of the velocity-curves is noteworthy, and is probably due to the fact that at several points in the tunnel are constrictions, often for some little distance, and the added friction produced by these results in more or less of a pumping-action. Undoubtedly, a more delicate recording-instrument would have shown the larger waves to be formed of a multitude of smaller ones. The movement of cars in the tunnel does not appear to have any decided effect upon the curves, although more delicate measuring-instruments might have shown it.

7. *Yellow Jacket Mine.*—Three levels of this mine are open

and operated from the old Yellow Jacket shaft. On the first level, the 900-ft., the air entering measures 3,075 cu. ft. per min. The air passes through a drift and thence down a winze to the 1,000-ft. level. The temperature and relative humidity of this air-current, at a point 500 ft. from the shaft, measured 66.2° F. and 55.6 per cent. respectively. The second, or 1,000-ft. level, receives 3,030 cu. ft. per min. from the shaft. Part of this air is taken by an air-pipe and conducted a distance of 350 ft. to a raise on the foot-wall of the vein, returns, joins the remainder, and then passes down through old stopes to the 1,100-ft. level.

The third, or 1,100-ft. level, is closed by a door in the drift, so as to force the air down the incline, which heads at this level, into an old station which is being reopened. The air escapes up through old stopes to the 1,100-ft. level. All the air passing down the Yellow Jacket shaft is brought together in the south drift, passes through a cross-cut to the old Belcher incline, and thence to the surface through the Belcher shaft. The amount of air passing through the drift measures 10,665 cu. ft. per min. The 900-ft. level of the Overman and Caledonia, corresponding to the 1,100-ft. of the Yellow Jacket, delivers 5,981 cu. ft. per min. to the Belcher shaft. The total quantity of air measured on this level is 16,646 cu. ft. per min., while the average passing up the Belcher is 31,706, leaving unaccounted for 15,060 cu. ft. per min. This comes from the lower levels of the Overman and Caledonia, but no measurement was possible at the time. The Yellow Jacket air at the foot of the Belcher incline gave a temperature of 79.7° and a relative humidity of 68 per cent.; the air coming from the Overman a temperature of 82.4° and a relative humidity of 62.3 per cent.

8. *Ophir and Belcher Upcasts.*—The measurements of both these shafts are to be found in Tables XVI. and XVII.

9. *Combination Shaft.*—The measurements for the Combination shaft are given in detail in Table XVIII. The numbered circles in Fig. 10 indicate the position in which the anemometer was held for each measurement.

Table XIX. has been calculated from the data of Tables XVI., XVII., and XVIII.

Since the cooling of the upcast air directly affects the effi-

TABLE XVI.—*Air-Measurements in Ophir Upcast Shaft.*

Date, 1908.	Pump.	No. 1.	No. 2.	No. 3.	Average.	Quantity.	Shaft-Temperature.	Relative Humidity, Shaft.	Surface-Temperature.	Relative Humidity, Surface.	Barometer.
						Cu. Ft. per Min.	Deg. F.		Deg. F.		
July 14, 11.45 a.m.	647	699	636	....	660	62,040	90.5	100+	73.4	30.45	24.2
July 17, 1 p.m......	532	506	480	....	506	47,564	......	100+	81.0	16.40	24.2
Aug. 8, 4 p.m.......	546	583	506	....	523	49,162	93.4	100+	87.8	18.40	24.0
Oct. 18, 2 p.m......	726	405	759	....	630	59,220	89	100+	40.0	....	23.8
Nov. 21, 4.30 p.m.	716	701	747	....	721	67,774	89	100+	45.0	61.2	23.7
Dec. 22, 5.30 p.m.	584	668	706	....	653	61,382	86	100+	40.6	26.5	23.97
Dec. 27, 3.30 p.m.	653	652	675	....	660	62,040	86	100+	43.3	50.1	24.0
Average...........	....	....	....	....	622	58,484	88.9	100+			

TABLE XVII.—*Air-Measurements in Belcher Upcast Shaft.*

Date, 1908.	No. 1.	No. 2.	No. 3.	Average.	Quantity.	Shaft-Temperature.	Relative Humidity, Shaft.	Surface-Temperature.	Relative Humidity, Surface.	Barometer.
					Cu. Ft. per Min.	Deg. F.		Deg. F.		
Oct. 10, 4 p.m......	620	567	323	595	27,720	......	100+	......	....	......
Nov. 8, 4 p.m......	656	612	525	598	30,611	......	100+	......	....	......
Nov. 15, 10.45 a.m.	760	717	525	667	36,375	74.3	100+	50	....	......
Nov. 22, 9 a.m.....	835	724	405	655	33,915	74.0	100+	50	....	......
Dec. 18, 3 p.m......	578	541	586	561	28,714	73	100+	26.6	49.2	24.2
Dec. 30, 11.45 a.m.	692	613	323	513	32,992	74.3	100+	44.6	50.2	23.9
Average.............	....	....	....	603	31,706	73.9				

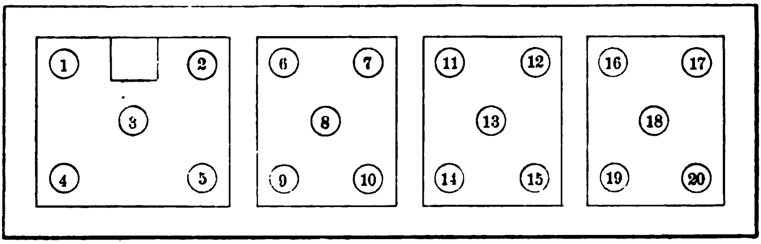

FIG. 10.—SECTION OF COMBINATION SHAFT, SHOWING POSITION OF ANEMOMETER.

ciency of the upcast shaft, the factors contributing to this are of some importance. I reached the following conclusions:

1. The greater the difference between the temperature of the upcast air and the rock-temperature, the greater the cooling-effect of the shaft.

2. The higher the temperature of the air entering the bottom of the upcast, the greater the cooling-effect of the shaft.

TABLE XVIII.—*Air-Measurements in Combination Shaft.*

Velocity, Feet per Minute.

Date, 1908.	Pump.						No. 1.					
	1.	2.	3.	4.	5.	Average.	6.	7.	8.	9.	10.	Average.
July 16....	110	315	330	200	405	272	312	400	312	350	570	389
Oct. 10.....	180	260	300	370	420	306	440	300	.....	.....	.....	488
Nov. 14...	560	500	452	500	510	504	630	520	.....	622	270	510
Nov. 15..	.....	.....	.....	.....	.....	353	930	481	.....	630	363	601
Nov. 21...	436	453	459	445	490	456	612	488	.....	622	402	525
Dec. 27.....	206	304	320	320	222	274	518	438	.....	526	286	442

Date, 1908.	No. 2.						No. 3.					
	11.	12.	13.	14.	15.	Average.	16.	17.	18.	19.	20.	Average.
July 16....	520	465	560	340	380	453	450	510	560	330	275	425
Oct. 10.....	.....	.....	.....	.....	.....	411	350	370	600	410	422	430
Nov. 14...	510	515	.....	530	418	494	520	590	620	406	615	549
Nov. 15...	540	470	.....	310	400	430	464	600	600	390	560	523
Nov. 21...	.....	.....	.....	.....	.....	556	479	617	638	490	584	561
Dec. 27.....	548	374	465	367	272	345	461	429	485	312	403	418

Cubic Feet of Air per Minute.

Date, 1908.	Pump C.	No. 1.	No. 2.	No. 3.	Total.	Average Velocity.
July 16....	10,472	11,670	13,590	13,750	49,482	385
Oct. 10.....	11,781	14,640	8,220	12,900	47,551	434
Nov. 14...	19,404	12,240	9,880	16,470	57,994	514
Nov. 15...	13,590	14,424	8,600	15,690	52,309	476
Nov. 21...	17,556	12,600	11,120	16,830	58,111	524
Dec. 27....	10,549	10,608	10,350	12,540	44,047	370
Average..	13,892	12,697	10,293	14,696	51,582	450

Date, 1908.	Time.	Temperature, Shaft-Collar.	Relative Humidity, Shaft.	Surface-Temperature.	Relative Humidity, Surface.	Barometer.
		Deg. F.	Per Cent.		Per Cent.	In.
July 16....	10.00 a.m.	80.6?	100+	65.3	29.9	24.35
Oct. 10.....	....	......	100+	......	......	....
Nov. 14...	3.30 p.m.	88	100+	50.0	......	23.92
Nov. 15...	3 to 4 p.m.	89	100+	52.9	33.8	23.90
Nov. 21...	3.00 p.m.	89	100+	42.8	65.0	23.70
Dec. 27.....	1.30 a.m.	84.2	100+	46.0	54.0	24.00
Nov. 16...	2.00 p.m.	87.0	100+	61.0	......	24.00
Nov. 17...	3.00 p.m.	88.0	100+	64.0	......	24.00
Nov. 18...	3.00 p.m.	88.0	100+	55.0	......	23.80

TABLE XIX.—*Relation Between Depth of Shaft and Cooling of Air-Current.*

Shaft.	Temperature at Foot.	Temperature at Collar.	Depth of Shaft.	Loss in Temperature.	Loss in Temperature, per 1,000 Ft. Depth.	Loss in Temperature, per 1,000 Cu. Ft. Air.	Loss in Temperature, per 1,000 Sq. Ft. Rubbing-Surface Per Min.
	Deg. F.	Deg. F.	Ft.	Deg. F.	Deg. F.	Deg. F.	Deg. F.
Ophir	102.1	88.9	1,600	13.2	8.25	0.22	0.06
Belcher........	81.0	73.9	1,200	7.1	6.00	0.22	0.07
Combination.	95.1	87.6	1,600	7.5	4.70	0.145	0.02

Average temperature of upcast air,	Ophir,	95.5°.
	Belcher,	77.4°.
	Combination,	91.35°.

3. The lower the velocity, and consequently the smaller the volume of air in the upcast shaft, with given area and rubbing-surface, the greater the cooling-effect of the shaft.

4. The greater the proportion of rubbing-surface to shaft-area, the greater the cooling-effect.

5. Where incast and upcast air are conducted through the same shaft, the cooling-effect of the incast upon the upcast air is very marked.

Regarding the effect of humidity upon the cooling-effect of the shaft, no definite conclusion was reached.

The recording-anemometer used in the Sutro tunnel was placed in the Ophir shaft, but no very satisfactory results were obtained on account of the failure of the instrument to operate in a vertical position. A special fan to operate in a horizontal position was constructed and connected with the recording part of the instrument by means of bevel-gears. The instrument was placed in the pump-compartment of the Combination shaft, calibrated in position by means of small anemometers, and three records taken. The results are given in Tables XX., XXI., and XXII. The factor 0.84 was used in reducing the velocities as given by the instrument to average velocities for the shaft. This factor was determined by taking the average values for the ratio of average velocity and center velocity.

The results from Table XX. are plotted in Fig. 11. The curves show the same characteristics as those of the Sutro tunnel, with the difference that the irregularities are more accentuated. The "pumping-action" of the shaft, due to constrictions, is clearly shown. The shaft is of uniform section, but the air-way leading to the bottom narrows down to about two-thirds the area of both branches of the Sutro tunnel on either side of the Combination partition.

Comparing Tables XVIII. and XXII., the average quantity of air passing is greater by 9,513 cu. ft. per min. for the 24-hr. measurements than for the average of the single measurements. The average minimum 24-hr. measurement compares closely with the average of the results shown by the single measurements. This result is to be expected, for the reason that the afternoon marks the period of the minimum velocities, and most of the single measurements were made in the afternoon.

TABLE XX.—*Air-Velocity Measurements, Combination Shaft.*

Observed Velocities, Miles per Hour.

Time.	Nov. 14 to 15.	Nov. 16 to 17.	Nov. 17 to 18.
4 to 5 p.m.	6.20	5.35	5.60
5 to 6 p.m.	5.50	5.50	5.35
6 to 7 p.m.	6.70	6.10	5.60
7 to 8 p.m.	6.70	6.30	5.80
8 to 9 p.m.	6.30	6.30	5.80
9 to 10 p.m.	6.70	6.30	5.95
10 to 11 p.m.	6.30	6.30	6.10
11 to 12 p.m.	5.80	6.30	5.60
12 to 1 a.m.	6.30	6.10	6.70
1 to 2 a.m.	6.70	6.70	6.30
2 to 3 a.m.	6.70	6.30	6.20
3 to 4 a.m.	6.80	......	6.30
4 to 5 a.m.	6.70	5.80	6.70
5 to 6 a.m.	......	6.70	5.80
6 to 7 a.m.	......	6.70	6.80
7 to 8 a.m.	6.30	6.10	6.10
8 to 9 a.m.	6.10	5.80	5.60
9 to 10 a.m.	5.80	5.80	5.80
10 to 11 a.m.	5.80	5.35	5.80
11 to 12 a.m.	5.80	5.80	5.35
12 to 1 p.m.	5.60	5.35	5.80
1 to 2 p.m.	4.80	5.35	5.35
2 to 3 p.m.	......	5.35	5.10
3 to 4 p.m.	......	6.10	5.50

TABLE XXI.—*Average Velocities Over Shaft Section.*

Date, 1908.	Average Velocity.		Maximum Velocity.		Minimum Velocity.		Time of Maximum Velocity.	Time of Minimum Velocity.
	Miles per Hour.	Feet per Minute.	Miles per Hour.	Feet per Minute.	Miles per Hour.	Feet per Minute.		
Nov. 15 to 16...	5.67	547.1	5.71	549.7	4.03	388.8	3 to 4 a.m.	1 to 2 p.m.
Nov. 16 to 17...	5.03	485.3	5.53	533.6	4.49	433.3	1 to 2 a.m.	12 to 3 p.m.
Nov. 17 to 18...	4.87	469.9	5.71	549.7	4.28	413.9	6 to 7 a.m.	2 to 3 p.m.
Average..........	5.19	500.7	5.65	544.3	4.26	412.0	1 to 7 a.m.	1 to 3 p.m.

TABLE XXII.—*Volume of Air in Cubic Feet per Minute.*

Date, 1908.	Average.	Maximum.	Minimum.	Shaft-Temperature.	Shaft-Humidity.	Surface-Temperature.	Barometer.	Time.
				Deg. F.	Per Cent.	Deg. F.	In.	
Nov. 15 to 16......	66,745	67,068	47,441	89	100+	52.9	23.9	Nov. 15, 3 p.m.
Nov. 16 to 17......	59,210	65,098	52,784	87	100+	61.0	24.0	Nov. 16, 2 p.m.
Nov. 17 to 18......	57,330	67,063	50,498	88	100+	64	24.0	Nov. 17, 3 p.m.
				88	100+	55	23.8	Nov. 18, 3 p.m.
Average.............	61,095	66,408	50,224	88	100+	58.5	23.9	

10. *Supplementary Ventilation.*—At the Ward shaft a No. 200 American, three-quarter housing, vertical-discharge, suction fan, driven by a 50-h.p. induction motor, is used to ventilate the workings of the shaft; and, as sinking is the only work, with the exception of the pump-stations, practically the full capacity of the fan is used for this work. The incast air passes down the two hoisting-compartments, and is deflected in part by a canvas curtain at the 2,475-ft. station (pump-station). The curtain is one-half the width of the compartment, and is suspended by its upper edge from a wall-plate on a level with the roof of the station. The lower edge hangs loose over the guard-bar in front of the compartment. This gives a curved surface and deflects enough air to ventilate the station, while allowing the cage, in passing down, to sweep it out of the way. The greater part of the air passes down to the sump and then rises through the pump-compartment, which is bratticed off from the hoisting-compartments.

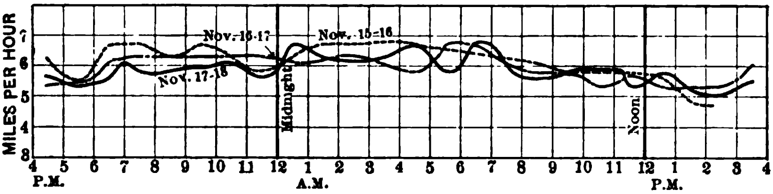

FIG. 11.—CURVES SHOWING RELATION BETWEEN OBSERVED VELOCITIES AND TIME OF DAY, COMBINATION SHAFT.

The discharge of the fan was measured several times. Five points were taken in the discharge section, and the average of the anemometer-readings was taken as the discharge velocity. Table XXIII. gives the results.

On December 13, at the 2,475-ft. level, the temperature in the station close to the down-cast compartments was 91.4° F., and the relative humidity 93.6 per cent.; in the upcast compartment on the same level the temperature was 104° and the relative humidity 100 per cent. plus. The upcast air was heavily charged with vapor.

The ventilating-effect of the fan is supplemented by the chimney-effect of the shaft. Calculating this effect, and not allowing for leakage through the brattice, a suction of 1.93 in. of water was obtained. This would leave 2.07 in. as the effect of the

TABLE XXIII.—*Air-Measurements of the Ward-Shaft Fan.*

Date, 1908.	1.	2.	3.	4.	5.	Mean Velocity.	Cu. Ft. Per Min.
July 19.....	2,842	4,200	3,556	2,842	3,576	3,476	105,280
Aug. 8......	2,248	3,860	3,464	2,280	3,292	3,028	91,597
Nov. 22....	2,760	3,428	3,044	2,628	2,944	2,959	89,510
Dec. 13.....	2,360	3,552	3,272	2,552	3,272	3,002	90,810
Mean	2,456	3,613	3,260	2,486	3,169	2,996	90,639

NOTE.—Only the last three readings were averaged, as the anemometer was not calibrated for the first reading.

Date.	Fan Discharge.		Air.		Time.
	Temperature.	Relative Humidity.	Temperature.	Relative Humidity.	
	Deg. F.	Per Cent.	Deg. F.	Per Cent.	
July 19......	......	......	......	......	9.00 a.m.
Aug. 8.......	90.0	37.0	88.34	14.0	9.00 a.m.
Nov. 22......	59.0	90.4	36.7	74.9	7.30 a.m.
Dec. 13......	55.4	94.3	36.5	56.5	12.50 a.m.

Water-gauge on suction side of fan gave 4 in. of water.

fan. The catalogue-rating of the fan is given as 75,700 cu. ft. per min. at 189 rev. per min. and an expenditure of 53.3 h.p. This would give, by difference, 14,939 cu. ft. per min. as due to chimney-draft. Calculation shows the chimney-effect to be equivalent to 17,088 cu. ft. per min. The difference between these two results is undoubtedly due to the catalogue-rating of the fan, which can be taken only in a very general way.

At the Ophir shaft a B. F. Sturtevant No. 16, double width, multi-vane fan is being installed. This fan is rated to deliver 140,000 cu. ft. per min. against a maintained suction of 2 in. of water at a speed of 200 rev. per min., with an expenditure of 100 horse-power.

The plan of the fan-arrangements at the Ward shaft is shown by Fig. 12 and at the Ophir by Fig. 13.

The distribution of the fans underground is given in Figs. 4 and 5, and the details of the fans in Table XXIV. The total horse-power of all motors used for ventilating purposes is 315; of this 150 is used on the surface and 165 underground. The actual horse-power in use, excluding the Ophir fan, which is being installed, is approximately 163.2. Of this 54 is used on

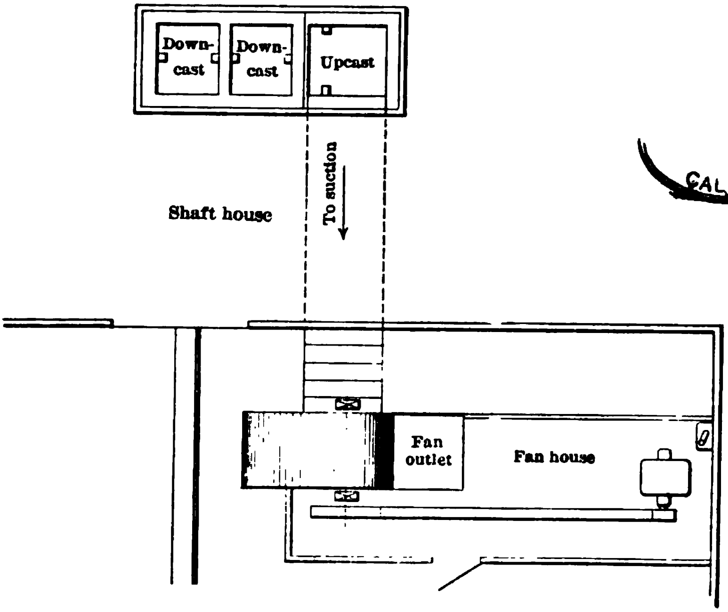

FIG. 12.—PLAN OF FAN AT WARD SHAFT.

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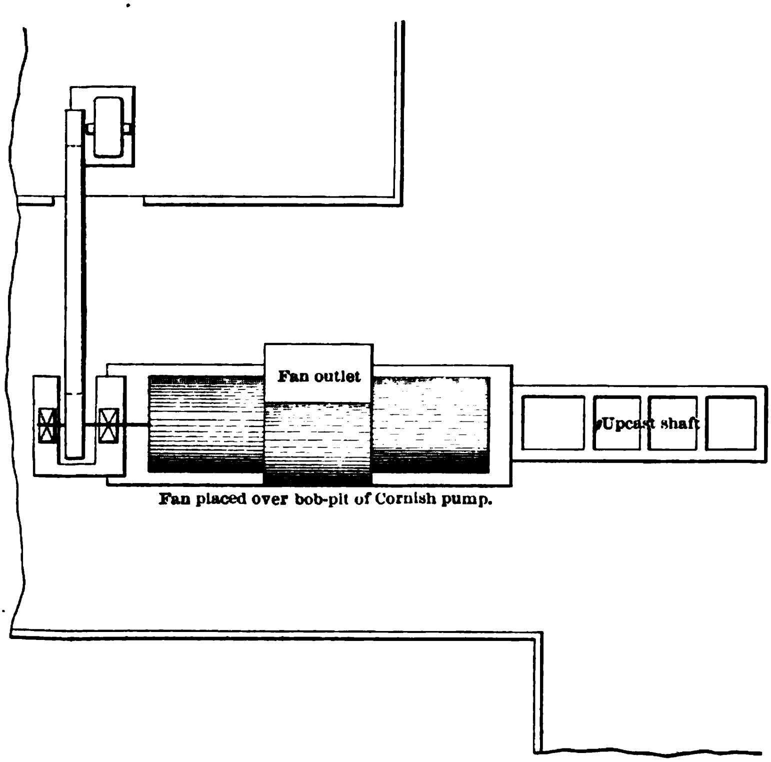

Fan placed over bob-pit of Cornish pump.

FIG. 13.—PLAN OF FAN AT OPHIR UPCAST.

TABLE XXIV.—*Fans in Use on the Comstock.*

Position.	Fan.	Motor.	Horse-Power.	Speed.	Air.	Diameter of Inlet.	Area of Inlet.	Diameter of Outlet.	Area of Outlet.	Diameter of Fan-Wheel.	Width of Fan-Wheel.	Notes.
		H.P.		Rev. per Min.	Cu. Ft. Per Min.	In.		In.				
Ward shaft	No. 200 metal exhauster	50	....	200	90,639	76	31.5 sq. ft.	....	31.25 sq. ft.	10 ft.	47 in.	
Ophir shaft	No. 16 double mine-fan	100	....	200	140,000	70	53.4 sq. ft.	....	53.8 sq. ft.	6 ft. 8 in.	7 ft. 4 in.	
Hale and Norcross, Sutro tunnel	15-in. metal exhauster	10	6	1,400	3,761	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	
Savage mine, Sutro tunnel	15-in. metal exhauster	10	6	1,000	2,357	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	
Gould and Curry, Sutro tunnel	15-in. metal exhauster	10	6	1,000	....	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	Not in operation.
Ward pump-station, 2,475 level	15-in. metal exhauster	5	2	....	....	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	
Union, 2,000 level	15-in. metal exhauster	10	8	1,680	4,287	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	Suction and exhaust.
Ophir, No. 1 fan	15-in. metal exhauster	15	4	1,000	8,791	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	
Ophir, No. 2 fan	6-ft. wooden fan	20	24	515	11,566	29	1,009 sq. in.	20 by 20	400 sq. in.	72 in.	20 in.	
Ophir, No. 3 fan	4-ft. wooden fan	5	4	360	3,328	20	406 sq. in.	16 by 16	256 sq in.	52 in.	16 in.	
Ophir, No. 4 fan	6-ft. wooden fan	15	9.6	340	....	29	1,009 sq. in.	20 by 20	400 sq. in.	72 in.	20 in.	
Ophir, No. 5 fan	6-ft. wooden fan	20	16	500	....	29	1,009 sq. in.	20 by 20	400 sq. in.	72 in.	20 in.	
Ophir, No. 6 fan	15-in. metal exhauster	20	14.4	1,500	5,389	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	
Ophir, No. 7 fan	15-in. metal exhauster	....	....	....	....	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	Not in operation.
2,150 Ophir, north workings	4-ft. wooden fan	5	1.2	360	....	20	406 sq in.	16 by 16	256 sq. in.	52 in.	15 in.	
1,000 level, Yellow Jacket	15-in. metal exhauster	10	....	1,000	....	15	176 sq. in.	15	162 sq. in.	22 in.	12.75 in.	Not in operation.
Overman-Caledonia	15-in. metal exhauster	10	....	1,680	4,900	16	201 sq. in.	16	201 sq. in.			

TABLE XXV.—*Accession of Moisture, Incoming Air-Currents.*

Sutro Tunnel.

Nov. 22, 1908.	Temperature.	Absolute Humidity.	Increase Humidity.	Distance.	Exposed Surface.	Volume.	Velocity.	Area.	Perimeter.	Area / Perimeter.	Grains per Square Foot per Hour.	Grams per Square Meter per Hour.
	Deg. F.	Gr. per Cu. Ft.	Gr. per Cu. Ft.	Ft.	Sq. Ft.	Cu. Ft. per Min.	Ft. per Min.	Sq. Ft.	Ft.			
Portal	46	2.08										
0–5,200	71.6	6.21	4.13	5,200	182,000	32,181	450	71.4	35	2.04	43.8	30.553
5,200–6,800	73	7.29	1.08	1,600	56,000	32,181	450	71.4	35	2.04	37.2	25.949
6,800–8,000	85.2	11.79	4.50	1,200	42,000	32,181	450	71.4	35	2.04	206.9	144.326
8,000–10,000	91.9	15.23	3.44	2,000	70,000	32,181	450	71.4	35	2.04	94.9	66.200
10,000–13,000	95	16.05	0.82	3,000	105,000	32,181	450	71.4	35	2.04	15.1	10.533
13,000–17,000	95	16.64	0.59	4,000	140,000	32,181	450	71.4	35	2.04	8.1	5.650
17,000–18,000	94.4	16.99	0.35	1,000	35,000	32,181	450	71.4	35	2.04	19.3	13.463
18,000–18,700	94.5	17.09	0.10	700	24,500	32,181	450	71.4	35	2.04	7.9	8.734
0–18,700	94.5	17.09	15.01	18,700	654,500	32,181	450	71.4	35	2.04	44.0	30.693
Ward S. connection, Dec. 13, 1908	87.8	11.147				South lateral.						
50 feet S. of H. & N. fan	108.86	14.184	3.037	2,720	89,760	10,143	161	63	33	1.90	20.59	14.363
North lateral partition	79.2	4.948				North lateral.						
C. & C. shaft connection	98.2	15.429	10.481	921	30,393	3,378	54	63	33	1.90	69.89	48.755
Drifts.												
2,350 west drift, section K	84.2	11.00										
2,350 west drift, near winze	98.6	18.77	7.765	580	12,190	11,667	413	28.25	23	1.23	561.4	391.62
2,350 east drift, end of pipe	89.6	5.93										
2,350 east drift, turn of drift, C.C	97.3	7.74	1.806	165	3,877	1,996	63	31.5	23.5	1.34	55.8	38.923
2,150 N. drift, section A	87.4	4.68										
No. 6 fan	98.6	7.123	1.443	660	15,510	7,024	223	31.5	23.5	1.34	39.2	27.345
Shafts.												
C. & C. surface	38.5	0.868										
C. & C., 2,150	59.7	3.944	3.076	1,900	82,650	33,212	431	77	43.5	1.77	74.17	51.739
Yellow Jacket, surface	34.7	1.036										
Yellow Jacket, 900 level	49.6	3.760	2.73	900	33,750	10,665	166	64.2	37.5	1.71	51.76	36.106
Union S., surface	46.8	0.766										
Union S., 2,000 level	65.1	5.688	4.922	2,000	134,000	13,814	109.6	126	67	1.88	30.4	21.206

the surface and 109.2 underground. With the Ophir fan in use the total horse-power approximates 263.2.

11. *Air-Pipes.*—The extensive ues of air-pipes warrants a detailed description.

The air-pipe is in 12-ft. lengths, 11-in. and 15-in. diameter being commonly used. No. 20 galvanized iron, in sheets 36 in. wide, cut to the necessary lengths for the diameters required, and with longitudinal seams punched, is delivered to the mine shop and there made into pipe as required. Longitudinal seams are riveted with $\frac{3}{16}$-in. rivets, 2.5-in. pitch; girth seams, 4-in. pitch. Longitudinal and girth seams are soldered. Joints are made with a bell, which is riveted and soldered to the pipe. Laps are 0.75 to 1 in. The mouth of the bell is strengthened with $\frac{3}{16}$-in. wire. The diameter of the mouth is 16 in. and the depth 4 in., not including the lap. This gives an over-all length of 12 ft. for each section.

The bell-joint is known as the "Southwell" joint. Elbows are made with an 18-in. radius, measured to the center of the pipe, and are provided with a bell-joint; the inside diameter of the mouth is 15.5 in.; the outside, 16.25 in. Rivets on transverse joints are pitched 2.5 in., and on longitudinal joints 1.5 in. Six pieces, including the bell, are required for each joint. The opposite end of the elbow has a diameter of 15.75 in. Right-angle tees, used for branches, are provided with two 11-in. dampers, having a clearance of $\frac{3}{16}$ in., and 15-in. dampers with a clearance of from $\frac{1}{8}$ to $\frac{1}{16}$ in. The dampers are riveted to a flattened $\frac{5}{8}$-in. iron rod, one end of which is bent so as to form a 6-in. handle. The damper is cut in the blacksmith-shop from $\frac{1}{8}$-in. sheet iron. Elbows of 45° are made from three pieces, including the bell. "Y" pieces and special breechings for the fans are made as required; 20-in. pipes, occasionally used, are made from No. 18 or No. 20 galvanized sheet-iron, with longitudinal seams riveted on 2.5-in. pitch, and girth seams from 5 to 6.75-in. pitch. The inside diameter of the bell-mouth is 20.75 in.; the outside, 21.25 in.; and the depth of the bell is 5 inches.

Air-pipes are suspended by **U**-shaped iron straps, made from $\frac{3}{16}$- and $\frac{1}{4}$-in. round iron, each end of the **U** being provided with a 3-in. point. The straps are driven into the timbers, three straps to each 12-ft. section. Where the air-pipe is placed in untimbered drifts, it is suspended by ropes or wire from plugs driven into drilled holes, or else from sprags wedged into place, and into which the iron strap-points are driven.

The bell-joints are made tight by wrapping several times with a tarred canvas strip 7 in. wide. Six or seven wrappings of 0.25-in. tarred cord are used to hold the canvas in place. New pipe, carefully wrapped in the manner described, allows very little air to leak through at the joints. Data on leakage will be given later in this paper.

If protected from acid mine-waters, and not battered by blasting, the life of an air-pipe is indefinite; but in wet shafts or where exposed to acid waters they frequently have to be replaced.

The shop-cost of 15-in. air-pipe is $8.50 per section; the cost of installation is nominal. The placing of a 15-in. air-pipe approximates $9.25 per section, or $0.77 per linear foot.

Air-Pipe Leakage.—Leakage depends very largely upon the care taken in wrapping the joints. If the ends are much battered the leakage may be considerable. Pressure and velocity of the air are minor factors.

A well-wrapped air-pipe extends from the Mint shaft to the Hale and Norcross workings. Connection is made with a fan at a distance of 1,500 ft. from the shaft. The discharge from this fan, at a distance of 230 ft., showed a loss of 411 cu. ft. per min., or a delivery of 89 per cent. of the inflowing air. The loss per joint is 2.93 cu. ft. per min. A water-gauge at the Mint shaft showed a pressure into the air-pipe of $\frac{13}{16}$ in. The continuation of the pipe, 267 ft. of 15-in. and 268 ft. of 11-in., or 535 ft. in all, gave an additional leakage of 1,941 cu. ft. per min. The pipe was not well wrapped, and the loss per section figures out 44.1 cu. ft. per min. In this case the suction created by the fan undoubtedly reduced the leakage on the 1,500-ft. section.

In the north lateral of the Sutro tunnel 120 ft. of 20-in. air-pipe showed a leakage of 122 cu. ft. per min., or 12.2 cu. ft. per section. The pipe was not wrapped, but was very carefully placed together.

In the Gould and Curry mine a leakage in 825 ft. of 15-in. and 11-in. pipe measured 437 cu. ft. per min., or 6.4 cu. ft. per min. per section. The pipe was partly wrapped and the air-pressure measured $\frac{13}{16}$ in. The fan was not in use.

In the Savage workings, with fan in operation and 15-in air-pipe, the leakage amounted to 1,610 cu. ft. per min. The length of 555 ft. of 15-in. pipe beyond the fan and 180 ft. of 11-in. pipe gives a leakage of 26.4 cu. ft. per min. per section. In this case most of the leakage took place on the last 180 ft. of 11-in. pipe.

Dampers showed a variable leakage, depending upon the perfection of the fitting and the care used in closing. Measurements showed from 10 to 180 cu. ft. per minute.

Two canvas curtains were measured: one showed a leakage of 1,635 cu. ft. per min. over an area of 35 sq. ft.; the other, 3,980 cu. ft. per min. over an area of 20 sq. feet.

The general conclusion is that leakage can be controlled within narrow limits by carefully wrapping the joints. A mile of 15-in. pipe with a leakage of 2.93 cu. ft. per min. per section would give a total leakage of 1,289 cu. ft. per min., and with an inflow of 4,000 cu. ft. per min. a delivery of 67 per cent. of the air is possible. This would be more than sufficient to ventilate an ordinary working-face. It is not always desirable to have a pipe tightly wrapped up to the face. Mr. Higginson informed me that with pipe tightly wrapped the blasts, if heavy, will cause much loss by collapsing. The practice is to wrap the pipe up to within from 200 to 300 ft. of the face and then leave the remainder unwrapped. Old and battered pipe is used close to the face.

Stops are constructed from timber or canvas; 1-in. rough boards, battened, are commonly used; doors are made from the same material; clay is used to stop small cracks and openings.

V. MEASUREMENT OF VENTILATING-CURRENTS.

1. *Temperature.*—The mine-measurements were made with an ordinary Fahrenheit thermometer of good grade. The instrument was suspended from a timber, and in approximately the center of the air-way. Unfortunately, this thermometer was not available for calibration. My observations were made with chemical thermometers carefully matched and compared.

2. *Velocity.*—All upcast shafts are housed in by wooden chimneys, which conduct the air outside the shaft-houses. Access to a shaft is had through doors, and from them most of the section may be reached. Five measurements were made in

as many positions in each compartment. The center and four corners were the positions selected, as shown by the numbered circles in Fig. 10. The corner position was taken 1 ft. from the timbers each way. The anemometer was held stationary in each position, and the velocity determined over a time-interval varying from 0.5 to 2 min. Observed velocities were corrected by the calibration-curve furnished by the maker of the instrument. Measurements were not taken by moving the instrument over the whole section on account of the difficulty of reaching some of the compartments. In part of the time during which measurements were made no work was done in the shafts, but during the remainder shaft-crews were at work in all three upcasts. The housing of the shaft at the collar prevented eddy-currents, and consequently all measurements were made in the plane of the shaft-collar. The time required to make from 15 to 20 separate measurements on one shaft varied from 30 to 50 min. Table XVIII. presents a complete set of observations for the Combination shaft.

The down-cast air was measured in one shaft only and at one time, since in all of the down-cast shafts work was going on. Difficulty was experienced on account of eddy-currents, even though the anemometer was held some distance below the collar of the shaft.

The center velocity of each compartment generally exceeded the corner velocities. The ratio between the two was calculated and an average of 1.19 obtained for the Combination, 1.09 for the Ophir, and 1.19 for the Belcher shaft. The reciprocal of 1.19 is 0.84, and this was used to calculate average velocities from center velocities. As an example of the use of this method for determining the average velocity, the following figures are given: The Ophir shaft was measured by both methods, Dec. 27, 1908. The average of five readings for each compartment was 653, 652 and 675 ft. per min., and the center velocities were 778, 732 and 732. Computing from these figures by the use of the constant 0.84, the following results were obtained: 690, 651 and 651 ft. per min. The average velocity by the 15 readings was 660, and the calculated velocity 664 ft. per minute.

Sections were taken in straight portions of the drifts where-ever these were available, and timbered sections were used in preference to the untimbered, but no special steps were taken to prepare sections of uniform cross-section. The anemometer was slowly moved over the whole section for a period varying from 0.5 to 2 min. Duplicate readings were generally taken.

On the whole, the measurement of the air in the air-ways of a mine, without special provision for smooth sections, is approximate only, and it is not possible to make very accurate measurements without resorting to extreme measures. My measurements were made during the working-hours of the mines, and without special provision for smooth sections.

The anemometers were of the Biram type, one 4-in. reading to 1,000 ft., one 4-in. reading to 100,000 ft., and one 6-in. reading to 1,000 ft. The recording-anemometer was a Julien P. Friez instrument, of the type used at the government meteorological stations. A sling-psychrometer was used in determining humidities, and the psychrometric tables published by the U. S. Weather Bureau were used in reducing results.

VI. Cost and Operating-Expense.

It is almost impossible to obtain detailed figures on the cost of the ventilating-system, but fairly accurate estimates may be made. The following estimate was made by taking the cost of motors and fans and adding 20 per cent. for cost of installation. The 15-in. air-pipe in place was estimated as $0.77 per ft. and 11- and 20-in. proportionally:

Cost of supplementary ventilating-plant:	
Motors,	$6,000
Fans,	6,000
Air-pipe,	10,000
	$22,000

NOTE.—The above does not include the cost of the fan and pipe in the Overman and Caledonia mines, nor the cost of electrical conduits.

Depreciation, maintenance, and operating-expense:	
Depreciation and maintenance assumed as 10 per cent. of plant-cost, or $2,200 per annum, or per month,	$183.30
Operating-cost:	
Power: 165 h.p., at $5 per h.p. month,	825.00
1 electrician, at $4 per day,	120.00
Incidentals,	50.00
Total expense per month,	$1,178.30

NOTE.—Shift-bosses and miners take immediate charge of fans and motors, and no extra men are employed except the electrician.

The expense of maintaining the upcast shafts may be properly charged against the cost of ventilation, and this is a large item, but at present no figures are available. During the past year shaft-crews of from four to six men have been employed on single shafts in all three upcast shafts for periods of from two to six months. On an average this work has to be done every second year.

On the foregoing estimate of expenses per month, the cost of each 10,000 cu. ft. of air passing through the mines is $0.00116, not including the cost of repair of upcast shafts.

VII. Underground Humidity.

In summer the air entering during the day is of low and in winter of moderate humidity. The temperature is neither excessively low nor high. The greater heat of summer is partly compensated for by the lower humidity, while the higher humidity of the winter months is compensated for by the lower temperature. The temperature of the entering air is of more importance than the humidity. The air-current begins to rise in temperature and absorb moisture as soon as it enters the underground workings. How rapidly it changes depends upon the velocity of the air-current, the difference of temperature between the air-current and the surrounding rocks, the relative humidity, and exposure of the air-current to moisture. The effect of these factors may best be studied from the three following examples:

1. *The Sutro Tunnel.*—Table II. and Fig. 2 are referred to. The temperature of the incast air reaches a maximum at a point 11,000 ft. from the portal. The temperature of the water controls the air-temperature. Humidity begins to increase as soon as the air enters the tunnel. For the first 6,800 ft. the air does not come in contact with the drainage-water, and consequently the moisture must come mainly from the walls.

The amount of moisture from this source is 43.8 grains per square foot of exposed surface per hour. Much of this part of the tunnel is untimbered. At the 6,800-ft. station the air comes in contact with the drainage-water, and absorbs moisture until it is almost saturated at a point 10,000 ft. from the portal, or after moving over the water for a distance of only 3,200 ft. The approximate exposed water-surface is 19,200 sq. ft. (average width of stream taken as 6 ft.). On the basis of the exposed water-surface the rate of accession of water-vapor is 798.5 grains per square foot per hour. The rapidity with which the air takes up moisture is remarkable. The rates for different parts of the tunnel have been calculated and are to be found in Table XXV. The total exposed surface, both rock walls and water, has been taken in calculating the table in preference to the water-surface alone. The results have been also graphically represented in Fig. 14. The rate for the whole tunnel up to the Combination partition is 44 grains per square foot per hour. For purposes of comparison, both north and south laterals for a portion of their length were calculated. The south lateral is timbered for about one-half the distance taken. Very little water drops from the walls, and the drainage-water is carried in a stave pipe, so that

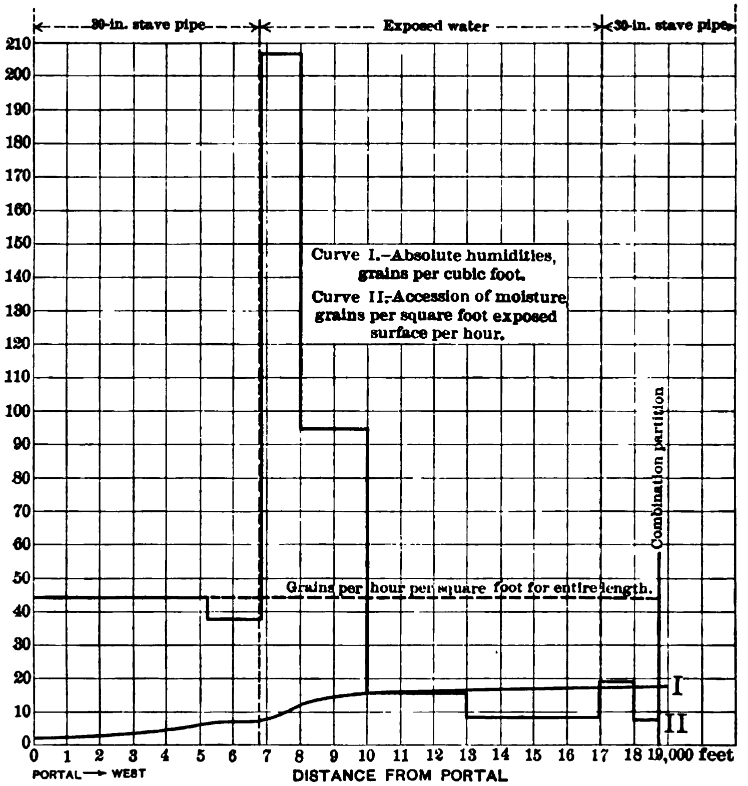

FIG. 14.—CURVES OF ABSOLUTE HUMIDITIES AND RATE OF ACCESSION OF WATER PER HOUR IN THE SUTRO TUNNEL, NOV. 22, 1908.

practically all the moisture comes from the walls. A rate of 20.59 grains was found. The north lateral, on the other hand, has open drain-boxes and more or less water is present, although the main flow of drainage-water is carried in stave pipes. The rate is 69.89 grains.

2. *Mine-Drifts.*—Three drifts have been calculated: the very hot west drift of the 2,350-ft. level; the east drift of the same level; and a portion of the 2,150-ft. drift. Although the west drift of the 2,350-ft. level is snow-shedded, the hot vapors find their way through with considerable freedom and give a high rate, 561.4 grains per square foot per hour. The east drift of this level is comparatively dry and practically out of the hot zone. It gives a much lower rate, 55.8 grains. The 2,150-ft. drift is also snow-shedded, but, since the lower workings have drained off the hot water to a great extent, the accession of moisture is very much less, 39.2 grains per hour.

3. *Down-Cast Shafts.*—Three down-cast shafts have been calculated: the C. & C. down to the 2,150-ft. level; the Yellow Jacket to the 900-ft. level; and the Union to the 2,000-ft. level. The range of temperature and the relative humidity at different levels in these shafts are shown in Fig. 15.

The C. & C. shaft is not a very wet shaft, but considerable moisture from the drainage-water is present from the 1,750-ft. to the 2,150-ft. level, which accounts for the high rate of 74.17 grains per square foot per hour. The Yellow Jacket is moderately wet, while the Union is quite dry. The rates are 51.76 and 30.4 grains respectively.

A better idea of the amount of water taken up by an air-current under high-temperature conditions may be gained by considering the total amount of moisture discharged with the air at the upcasts. The total amount in all upcasts is 519,788 lb. per 24 hr., divided as follows: Combination, 146,330; Ophir, 172,140; Belcher, 58,941; Ward, 142,377 lb. These quantities have been calculated on the average amounts of air as given in Table III. Assuming an average temperature of 60° F. and a relative humidity of 50 per cent., the down-cast air brings into the underground workings 127,990 lb. of moisture per 24 hr., which leavea 391,798 lb. of water per 24 hr. as the amount taken up by the air-currents. The calculated result is somewhat less than the actual amount.

The unit used in comparing different mine-workings is the rate of accession of water vapor per square foot of exposed surface per hour, and is calculated from the following ratio:

$$\frac{\text{Volume of air in cubic feet per minute} \times \text{increase in absolute humidity per cubic foot for the length under consideration} \times 60\text{ min.}}{\text{Square feet of exposed surface in length under consideration, or length of air-way} \times \text{perimeter.}}$$

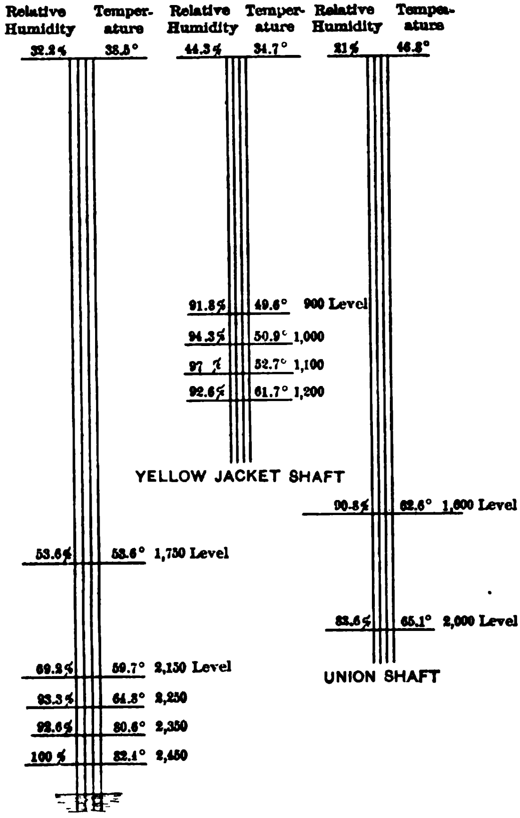

FIG. 15.—RANGE OF TEMPERATURE AND RELATIVE HUMIDITY IN DOWN-CAST SHAFTS.

VIII. CONTROL OF HUMIDITY AND HEAT.

Control of humidity and heat is a matter of considerable importance as affecting the efficiency of the miners. High temperatures and saturated air are conducive to low labor-efficiency, while, on the other hand, high temperature with low humidity does not lower efficiency to an unreasonable extent. The examples in the previous section show that if water can be kept away from the air a moderate humidity is possible, but this cannot always be done. Careful boxing of drains and boarding-off of hot water are beneficial; the carrying of large quantities of drainage-water in closed conduits, such as the stave pipe, is very effective, but, on the whole, the mine-drift or tunnel cannot be considered an ideal air-way under high-temperature conditions. However carefully the drainage-water may be carried, the emanation of water-vapor from the walls and surfaces of the timbers still remains as an important humidifying-agent. The construction of moisture-tight walls for the drifts is out of the question, and the use of excessive volumes of air is impracticable. The carrying of air through sheet-metal conduits of moderate cross-section is the only practicable way of delivering air-currents of low humidity to working-places where a high temperature prevails, and this method is in general use upon the Comstock. The small size of the air-pipe as compared with the drift requires the use of power-driven fans to force a sufficient quantity of air. The working-face of a dead end, such as a drift, is perhaps the most difficult to maintain in proper condition, and as a consequence a number of measurements were in the ends of drifts ventilated by pipes. These measurements are given in Table XXVI.

With the exception of two cases the air is delivered practically either at the temperature of the working-face or a little above. The two exceptions indicate that if a sufficient volume is forced through the pipe the air can be delivered lower in temperature than the working-face, although usually the volume is such that even with short distances the air is delivered at the same temperature as the drift through which the return current is passing. The quantity of air varies from 500 to 1,200 cu. ft. per min., in ordinary cases, up to from 2,000 to 4,000 cu. ft. per min. in cases in which an excessive temperature is to be overcome. The humidity of the discharged air depends upon the humidity of the air entering the pipe or fan and the temperature of the discharged air, and for this reason the air should be drawn from a current low in both temperature and humidity. The relative humidity of the discharged air ranged from 20 to 41 per cent., while the relative humidity at the face, usually 20 to 25 ft. beyond, ranged from 22 to 74.4 per cent.

TABLE XXVI.—*Air- and Temperature-Measurements at Drift-Ends.*

Place.	Temperature of Discharged Air.	Temperature of Working-Face.	Relative Humidity of Discharged Air.	Relative Humidity of Working-Place.	Distance of Working-Face from Pipe-End	Cubic Feet of Air per Minute.	Velocity of Discharge.	Diameter of Air-Pipe.
	Deg. F.	Deg. F.	Per Cent.	Per Cent.	Ft.		Ft. per Min.	In.
Large Volumes of Air.								
2,350 C. & C. shaft, west drift	82.4	110	....	100	25	4,160	3,492	15
2,350 C. & C. shaft, east drift	89.6	96.8	40.6	50.7	40	1,996	2,050	15
Moderate Volumes of Air.								
Gould and Curry, Sutro tunnel	91.0	91	31	31	12	989	1,521	11
Savage, 75 ft. above Sutro tunnel	92.6	92.1	37.3	51	30	894	1,356	11
Chollar, Sutro tunnel	104.5	....	23.8	....	....	934	1,416	11
Chollar, Sutro tunnel	106 2	106.2	22	22	10	721	1,104	11
Hale and Norcross, cross-cut	106.1	107.6	21.8	32 2	15	941	1,426	11
Hale and Norcross, cross-cut	109.4	109.6	20.0	29.8	25	688	1,054	11
2,000 level Union, NW. cross-cut	99.1	98.6	38.3	43.4	20	1,271	1,042	15
2,000 level Union, south drift	98.6	....	40.8	....	30	971	796	15
2,350 C. & C.. north workings	104.5	....	36.5	....	....	544	490	15
1,200 level, Caledonia	86.0	87.8	41.0	74.4	25	792	1,200	11
No Active Circulation of Air.								
2,000 level, Union, east cross-cut	....	100.9	....	74.8				
1,100 level, Yellow Jacket, north drift to Imperial.	....	89.9	....	86				

The first drift in the table, the west drift of the 2,350-ft. level of the C. & C., illustrates abnormal conditions. Great heat and a large quantity of moisture emanated from the rock walls, which had not at the time been closed off by boarding, and this charged the air-current to saturation and raised the temperature 27.6° F. in a very short distance. The east cross-cut of the Union on the 2,000-ft. level is a dead end, in which practically no air was circulating, and which was also dry. The north drift on the 1,100-ft. level of the Yellow Jacket is also a dead end, without circulating air, but with a small amount of water on the floor of the drift. In neither of these drifts was the air saturated with moisture, but in both it was quite oppressive.

The principle and use of the air-pipe as a means of delivering low-humidity air-currents is of course no new thing. Church comments upon the efficiency of the system, and in particular notes that by forcing the air through metal pipes the relative humidity of the air-current is lowered and it becomes quite effective in absorbing the excessive perspiration of the miners. The only improvements to be noted in Comstock practice since the time of Church's observations, about 30 years ago, are an increased velocity and a larger quantity of air, larger air-pipes, the use of high-speed metal fans instead of the slower wooden fan, the use of electric motors instead of compressed-air engines, and the use of more power.

Supersaturation of air-currents, resulting in the production of fog, is encountered in all of the upcast shafts near the surface, and in all places underground where cool currents mix with hot saturated air. The moisture condenses on timbers and rock-surfaces, and frequently causes the rock to swell, disintegrate, and cave. By stimulating the growth of fungi it also indirectly causes the timbers to rot. In only one place is any attempt made to remedy such a condition, and in this case a small amount of cool air is introduced into the air passing up the Ophir incline. Trouble was experienced in this incline by the condensed moisture causing the "back" to swell, and the remedy was found effective. It is evident that the introduction of cool air lowers the temperature of the upcast air and thus reduces the efficiency of the upcast, and if too much air is introduced the opposite from the desired effect would be obtained. Passing the air through the shortest and driest air-ways to the upcast, and the careful stopping of all leaks of cool air, would be a more effective way than that now followed.

Some observations upon the cooling-effect of large volumes of air were made. The most striking results were in the case of the hot west drift on the 2,350-ft. level of the C. & C. Before the connection was made the maximum temperature of this drift varied from 126° to 130° F., and this in spite of forcing 4,160 cu. ft. of air per minute into the face. The air in the drift was saturated and would not support a candle-flame. After making the connection and before boarding-off the walls of the drift, the temperature dropped to 110°, with a volume of air passing of 10,350 cu. ft. per min. The air-current was supersaturated. After snow-shedding, the temperature dropped to 98.6°, with 11,667 cu. ft. per min. passing and a relative humidity of 98.8 per cent. In the Hale and Norcross cross-cut, on Dec. 28, the rock-temperature measured 113° and the air-temperature 109.6°. The reduction in temperature of more than 3.4° was effected by an air-current of 688 cu. ft. per minute.

The most effective means for the control of an excessive temperature is the tight boarding of water-boxes carrying hot water, the use of boards and battens for the sides and tops of drifts, and passing large volumes of air as cool as possible.

IX. Physiological Effect of Working in High Temperature and Humidity.

Much has been written regarding the effects upon the human system of poisonous and other gases, but very little is to be found in mining-literature concerning high temperature and humidity. Le Neve Foster says:[5]

> "In still and saturated air it is hardly possible for men to do hard continuous work above 80° or 85° F., even when stripped to the waist. At higher temperatures in saturated air the amount of work possible becomes less and less, and the body temperature may rise rapidly, though men accustomed to the heat can bear it much better than others. At temperatures above about 90° by the wet bulb it is only possible to work for short periods, and it becomes difficult even to remain without working. Thus, at a temperature of 93° in still and saturated air, I found that, though I was stripped to the waist and doing practically no work, my temperature rose 5° in two hours, and was still rising rapidly when I found it necessary to come out. On the other hand, it is a well-known fact that if the air is dry much higher temperatures can be borne with ease and comfort. In collieries

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[5] *Investigation of Mine Air*, Sir C. Foster and J. S. Haldane, p. 151 (1905).

where the air is fairly dry and in motion, men can work well at a dry-bulb temperature of 90°, or even 100°, and in hot climates with very dry air much higher temperatures are not oppressive."

Eliot Lord[6] discusses the permanent effect of high heat upon the system, and reaches the following conclusion:

"The ultimate effect of this extreme heat on the miners' constitution is not so easily noted. The mine levels differ so materially in temperature, and the assigned station of a miner is so frequently changed from one cause and another, that it is impossible to obtain at present complete comparative data. That prolonged labor in a hot, impure atmosphere will assuredly shorten life appears indisputable; but whether the system is permanently or materially injured by intermittent working under those conditions is more questionable. The power of recuperation appears extraordinary, and, unless the strain is intense and frequent, no lasting injury may be inflicted. The limits of permissible strain will, of course, vary with the relative power of endurance. The action of all the bodily organs appears to be stimulated by the heat, with the exception of the stomach alone."

Messrs. Haldane and Thomas[7] comment on exposure to high temperatures and sudden variations of temperature as follows:

"Miners are commonly exposed to high temperature underground, and to comparatively sudden cold on coming out, often with damp clothes on. Much stress has been laid on this fact, particularly in relation to lung diseases. Nevertheless, this cannot be an important cause of lung disease, for colliers are similarly exposed. Moreover, in England, colliers never wash and change their clothes at the pit-head, while Cornish miners almost invariably do so, in a heated building ('dry') provided on the mine. The effects of high underground temperatures on men and horses are certainly of considerable interest and economic importance, and we know from personal observations that in warm and moist air underground the body temperature often rises several degrees; but we can find nothing in the circumstances connected with the mode of occurrence of miners' phthisis to suggest that high underground temperatures are in any way connected with its causation."

Church writes[8] on the immediate results of high temperatures and hot vapors, as absent-mindedness, dizziness, fainting, vomiting, and, as graver results, insanity and death. His final conclusion is the following:

"The casualties positively traceable to the heat are therefore twelve per cent. of the whole. Probably the heat increases the bad effects of powder fumes and natural gases, and by making repairs to the shafts more frequently necessary it indirectly adds to the occasions when disasters may occur. I also confess to the belief, which is not sustained by observations upon specific casualties, that some allowance should be made for a less active mental condition, a dulling of the faculties, and a certain recklessness to which the heat sometimes goads the men. On the other hand the heat makes them more cautious except when under momentary impulses, and I have never seen American miners more careful of themselves than in these mines. On the whole the good and bad effects of the heat seem to nearly balance each other, and I think that an allowance of five per cent. for the casualties indirectly caused by the high heat would be sufficient."

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[6] Comstock Mining and Miners, *Monograph IV.*, *U. S. Geological Survey*, p. 400 (1883).

[7] *Transactions of the Institution of Mining and Metallurgy*, vol. xiii., p. 383 (1903–04).

[8] Accidents in the Comstock Mines and Their Relation to Deep Mining, *Trans.*, viii., 95 (1879–80).

The main facts brought out by these observers are that high temperatures and humidities cause, under some conditions, a notable rise in body-temperature; that all the bodily organs with the exception of the stomach are stimulated; that prolonged exposure to such conditions undoubtedly lowers vitality; that intermittent exposure produces no permanent ill-effects; that these conditions cannot be considered an important cause of lung-diseases; and, lastly, that under abnormal conditions loss of mental control and serious bodily disturbances result.

Local physicians inform me that the average life of the Comstock miner approximates 25 years, and that the miners do not show any greater susceptibility to any particular disease than the residents of the town. I am acquainted with miners who have worked more or less continuously underground for 30 years, and who are still capable of doing a good day's work. Compared with miners of other districts the Virginia City miners may be said to be just as healthful, if not more so. The result is due in a large measure to the fact that the Virginia City miner observes certain precautions, and that the mine-managements provide the necessary facilities. Miners are careful not to expose themselves to cold drafts, since they work stripped to the waist. On passing from a hot to a cold place a heavy coat is used to protect the heated body. Wet clothes are either removed before going to the surface, or trousers and coat worn over them. All miners take hot and cold showers after coming off shift. Frequent drinking, and the bathing of the hands, wrists, arms, and head in ice-water are resorted to in all hot workings, and undoubtedly serve to keep down the body-temperature, while temporarily refreshing. Frequent rests are taken in special cooling-rooms, so placed in the workings as to receive the freshest and coolest air. In exceedingly hot workings cold water from a hose is turned upon the miner while at work.

The effect of the underground conditions upon the blood was made the subject of a preliminary study by Prof. P. Frandsen at my request. His results are of importance, and in consequence are given in full in the accompanying note. His conclusion, given tentatively, is that "the conditions in the deep workings of the Virginia City mines do not have any particularly detrimental effects upon the composition of the blood. From a comparison of Tables XXVII. and XXIX. it appears that the main permanent effect is an increased hæmoglobin-content of the individual red blood-corpuscles."

Conditions are not favorable for a study of the comparative efficiency of miners working under normal temperatures and under those in the lower levels of the Comstock. The following conclusions are the results of my underground experience: Moderately high temperatures, from 95° to 105° F., with moderate humidities, from 50 to 70 per cent. relative humidity, and with air-currents of velocities from 200 to 300 ft. per min., do not prevent efficient work nor are they particularly uncomfortable.

A higher temperature, from 110° to 115°, together with the same conditions as above, decreases efficiency to a considerable extent.

A high temperature, from 110° to 115°, with high humidity and moderate velocity air-currents, very greatly impairs the miners' efficiency; and a still higher air-velocity, under the same conditions, renders workings more bearable, but miners cannot work very long at one time.

A moderately high temperature, from 95° to 105°, in a saturated atmosphere with no current, becomes very trying. Prolonged exposure with much exertion is dangerous.

A moderate temperature, from 90° to 98°, and saturated air-currents of a velocity of from 400 to 500 ft. per min., with more or less vitiated air, are conditions which are very trying and give a low labor-efficiency. Vitiated air will impair labor-efficiency to a greater extent than a high temperature.

X. APPENDIX.

By PROF. P. FRANDSEN.*

With a view to obtaining more exact information as to the physiological effects of the atmospheric conditions in the lower levels of the Virginia City mines, some preliminary studies were made upon the blood of subject No. 1 and several miners. To determine the effect of a temporary sojourn in the mines, blood of subject No. 1 was examined at Reno, December 10, two days before going to Virginia City; December 12, after remaining 2.5 hr. in the 2,000-ft. level of the Union shaft; on December 13, after spending 4.5 hr. in the Sutro tunnel and south lateral; and on December 14, at Reno. The temperatures in the workings visited ranged from 100° to 109°, with humidities of from 60 to 100 per cent. During both trips the subject and myself perspired profusely while underground, but felt no ill-effects other than a slight dizziness and a natural fatigue. The results of the examinations are given in Table XXVII.

TABLE XXVII.—*Subject No.* 1.

Date.	Place.	Red Corpuscles per c.c.	Leucocytes (white corp.) per c.c.	Hæmoglobin. Per Cent.	Hæmoglobin Index.
Dec. 10...	Reno........................	5,160,000	7,111	95	92
Dec. 12...	Va. City, underground	4,820,000	12,333	...	...
Dec. 13...	Va. City, underground	6,496,000	12,277	100	77
Dec. 14...	Reno........................	6,220,000	9,888	95	76

The difference in red-counts on December 10 and December 12 may be ignored as too slight to have any significance. On December 13, however, after the longer sojourn underground, there was an appreciable increase of red corpuscles, which is still to be noted on the following day. On both occasions there was a considerable leucocytosis, due mainly, as Table XXVIII. shows, to an increase in the number of neutrophiles.

Tables XXIX. and XXX. give the results of examinations of five miners who have been engaged in mining for 10 years or more, and for a year or more have been at work under the conditions described in this paper as characteristic of the deeper

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* Professor of Biology, University of Nevada.

TABLE XXVIII.—*Differential Count of Leucocytes (White Blood-Corpuscles).*

Date.	Leucocytes per c.c.	Percentage of Varieties.				
		Lymphocytes.	Mononuclears.	Neutrophiles.	Eosinophiles.	Mast.
Dec. 10..	7,111	41.5	2.5	55.5	0.4	0.1
Dec. 12..	12,333	32.0	2.0	65.0	0.9	0.1
Dec. 13..	12,277	32.8	2.4	64.1	0.5	0.2
Dec. 14..	9,888	44.6	3.7	49.0	2.5	0.2

levels. All the subjects were in a fair state of health, and men of good physique, well nourished, and moderate users of tobacco and liquor. The examinations were made as soon as the men reached the surface at the close of their day's shift, and, except in the case of subject No. 2, before the shower which all take at the end of the day's work.

TABLE XXIX.—*Summary of Examinations of Blood of Miners.*

Subject.	Age.	Red Corpuscles per c.c.	Leucocytes per c.c.	Hæmoglobin.	Hæmoglobin Index.	Pulse.	Temperature.
				Per Cent.			
2	38	4,236,000	6,000	115	1.35	80	97.4
3	29	5,386,000	7,814	120	1.11	76	97.2
4	33	4,460,000	10,777	120	1.34	70	98.2
5	38	5,178,000	7,055	111	1.07	80	98.2
6	38	5,422,000	12,277	114.5	1.05	61	99.1

TABLE XXX.—*Differential Count of Leucocytes of the Blood of Miners.*

Subject.	Leucocytes.	Percentage of Varieties.				
		Lymphocytes.	Mononuclears.	Neutrophiles.	Eosinophiles.	Mast.
2	6,000	36.8	5.8	56.6	0.4	0.4
3	7,814	52.4	3.2	48.5	0.5	0.4
4	10,777	40.7	3.5	54.0	1.0	0.8
5	7,055	53.3	2.3	43.1	0.8	0.5
6	12,277	34.3	3.7	59.1	2.8	0.7

The most striking feature revealed by Table XXIX. is the uniformly high hæmoglobin index of the miners' blood. The percentage of hæmoglobin was determined by means of Dare's instrument. In two cases only is the number of red corpuscles below the normal average, 5,000,000 for persons at sea-level; but the reduction is hardly great enough to be considered indicative of anæmia. Moreover, microscopic examination of stained preparations showed no abnormal appearances. The red corpuscles were of uniform size and shape, and chiefly noteworthy for their richness in hæmoglobin, indicated by the intensity and uniformity with which they took the eosin stain. The foreman said of subject No. 2 that he did not stand the heat as well as the other men, and had fainted on several occasions.

Except possibly in the cases of subjects Nos. 1 and 6, the leucocyte-counts are within the limits of variability in normal individuals. Most striking is the high percentage of lymphocytes, particularly in subjects Nos. 3 and 5.

As living in high altitudes is claimed by many authorities to bring about a marked increase in the number of red corpuscles over the number normal to residents of the sea-coast, I give in Table XXXI. for comparison with Tables XXVI. to XXX. the results of counts made upon subjects resident in Reno and Virginia City, all of whom were in good health and had resided in the locality designated for a number of years.

TABLE XXXI.—*Summary of Blood-Examinations in Relation to Altitude.*

Subject.	Age.	Red Corpuscles per c.c.	Leucocytes per c.c.	Hæmoglobin.	Hæmoglobin Index.	Place.	Altitude.
				Per Cent.			Ft.
1	32	5,160,000	7,111	95	92	Reno.	4,553
7	32	5,399,000	8,944	105	97	Reno.	4,553
8	33	5,536,000	8,944	109	98	Va. City.	6,000
9	40	6,074,000	6,777	104	85	Reno.	4,553
10	20	6,378,000	4,111	110	86	Reno.	4,553

Subject No. 9 for several years has been making regular and frequent trips to the summit of Mount Rose, elevation 10,800 ft., and is an experienced mountain-climber. The examinations of both Nos. 9 and 10 were made about 24 hr. after their return from a fatiguing three days' trip to the summit of this mountain.

These counts do not show as great an increase in the number of red corpuscles as the published accounts of other observers would lead us to expect in these altitudes. In comparison with these results, the number of red corpuscles obtained in the counts on the miners would not seem to be very far from the normal. Differential leucocyte-counts were made on the blood of these subjects, as given in Table XXXII.

TABLE XXXII.—*Differential Count of Leucocytes in Relation to Altitude.*

Subject.	Leucocytes per c.c.	Percentage of Varieties.				
		Lymphocytes.	Mononuclears.	Neutrophiles.	Eosinophiles.	Mast.
		Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	7,111	41.5	2.5	55.5	0.4	0.1
7	8,944	33.4	4.5	57.6	3.5	1.0
8	8,944	32.2	5.4	60.4	1.7	0.3
9	6,777	44.4	5.2	49.2	1.0	0.2
10	4,111	42.0	5.5	50.0	2.1	0.4

The only point to be noted is the relatively high percentage of lymphocytes.

While these studies are too few to warrant an extended discussion or the statement of any very definite conclusions, they are of interest as indicating that the atmospheric conditions in the deep workings of the Virginia City mines do not have any particularly detrimental effects upon the composition of the blood. From a comparison of Tables XXIX. and XXXI., it appears that the main permanent effect is an increased hæmoglobin-content of the individual red corpuscles.

ACKNOWLEDGMENTS.

In collecting the foregoing data I received many courtesies from the officials of the Ophir mine, the Sutro Tunnel Co., the Yellow Jacket Mining Co., the Caledonia, and Overman Mining Cos. I wish especially to acknowledge the assistance of Dwight T. Smith, of the Virginia Mining School; T. McCormick, superintendent of the Ophir mine; T. Sullivan, of the Ophir mine; B. O'Hara, foreman of the Sutro tunnel; and Leon M. Hall, of the Ward Shaft Pumping Association. To Professor Frandsen, for his contribution, I am particularly grateful.

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SLIME-FILTRATION

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Slime-Filtration.

BY GEORGE J. YOUNG,* RENO, NEV.

(San Francisco Meeting, October, 1911.)

THE nature of slimes handled in the treatment of gold- and silver-ores has been discussed in technical literature to a considerable extent. The subject of slime-filtration from the practical worker's stand-point has also received much comment, and scattered through the literature of the subject are descriptions of many slime-filtration installations. Articles of this nature serve a valuable purpose and assist materially in the design of new and the improvement of old plants. The subject of the physics of slime-filtration has been touched upon to only a slight extent. The underlying principles are worthy of more intensive study and experimentation than they have received, and the main purpose of this paper is to present the results of such study and experimental work as will serve to make clear in part at least many of the principles which control the filtration of slime.

Nature of Slime.

Much has been written concerning an accurate definition of the term "slime," but no comprehensive definition seems to be generally accepted. The reason for this is clear. A slime consists of at least three different substances, each, when separated, possessing distinctly different physical and to a certain extent chemical properties. These substances are extremely fine sand, a colloidal material which may be and generally is in a coagulated condition, and a colloidal material which is in a non-coagulated condition. Suspending a slime in a relatively large volume of water by shaking and allowing sedimentation to take place, results in the fine sand settling out with comparative rapidity, followed by the coagulated material, which settles much more slowly and finally a certain portion remains electric current was shut off. A hose was then turned on the fire, but the dense smoke drove the attendant out. Inspection by the electrician and the shaft-foreman, equipped with oxygen-helmets, soon after, showed no flames or excessive heat, but the continued expulsion of smoke indicated that some fire was present. The pump-chamber was then ordered flooded. No estimate of the damage was published and no fatalities occurred.)

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It is not the purpose of the present paper to discuss the above examples, but rather to use certain features of them to formulate general plans which might be of use in fire-prevention and fire-fighting.

In the above list three fires are noteworthy in that they originated in wooden shaft-houses and communicated with workings underground, resulting in considerable damage. The risk taken by closing in the mouth of a shaft with wooden buildings has long been recognized, and most of the Western mines have eliminated the shaft-house. In Virginia City, on account of the severe winters, the shaft-house has been retained, but, following the lesson given by these three fires, and the passage of a mining-regulation governing this feature of mine-construction, active steps have been taken to remove the risk. In almost every case where the shaft is used as a working-shaft wooden buildings about the shaft-mouth have been removed.

Mine-fires may be considered in two groups: those which occur in the surface-plant and those which occur in the underground workings. Fires in mine surface-plants do not, as a rule, result in loss of life, and if proper fire-fighting facilities are provided, the fire may be extinguished with but moderate loss. In Nevada considerable progress in the use of fire-proof construction has taken place in recent years. The following steel and semi-fire-proof constructions may be noted: Goldfield Consolidated mill, Goldfield; New Belmont mill, Tonopah; Nevada Consolidated concentrating-mill, McGill; Nevada Reduction Works mill, Dayton; Nevada Hills mill, Fairview; Pittsburgh Silver Peak, Blair.

Steel head-frames: Montana Tonopah, Tonopah; Tonopah of Nevada, Tonopah; Union shaft, Virginia City; Star Pointer shaft, Ely; Merger mines shaft, Goldfield; Giroux mine, Kimberly.

The protection of the surface-plant from fire is recognized as a necessity, and most mining companies, where an extensive plant has been installed, provide facilities of some sort for fire-fighting. In the design of a surface-plant the question of fire-risk should receive considerable attention. The segregation of different parts of the plant, the separation of each unit by a sufficient distance to prevent the spread of a fire from one unit to another, and, finally, the use of materials which are either fire-proof or of a slow-burning nature, are the main points which deserve consideration at the start. While it is true that the use of expensive materials and equipment is not warranted in the early stages of a mine's development, it is often the case that after a mine has reached the producing stage the same types and materials of construction are used, and a surface-plant grows until it involves an amount of combustible material that in itself is a risk of some magnitude. The inevitable happens, a fire gets beyond control, and the destruction of the plant follows; this occurs in spite of what were deemed adequate fire-fighting facilities.

That a more general use of fire-proof and semi-fire-proof materials and construction in Western mines is merited goes without saying. That there is progress in this direction no one familiar with the more recent camps of the West can deny. It may not be out of place here to review the different types of building-construction used for surface-plants. They may be enumerated:

1. Timber frame with board siding.
2. Timber frame with corrugated-iron siding and roof.
3. Steel frame with curtain-wall construction in which brick, ferroinclave, and cement plaster or reinforced concrete is used.
4. Reinforced concrete.
5. Brick walls, steel frame, and corrugated-iron roofing.

In Nevada the first two methods of construction are common in the case of most mines and prospects. Of these, the second method is preferable on account of reducing the amount of combustible material. By whitewashing the timber-work both ignition and the spread of a fire may be retarded. The third method of construction is in use where large plants, more or less permanent in their nature, are erected. Examples have been cited above. The fourth method is quite common in coal-mine surface-plants in Westphalia, Germany, but is not often met with in the Western States of America. It merits consideration by the mining engineers of the United States. The use of reinforced concrete is uncommon, but some examples are to be recorded in Nevada. The Midway mill, erected in the early days of Tonopah, was constructed with steel frame and corrugated-iron siding, and contained a reinforced-concrete ore-bin. In the Belmont mill and the Goldfield Consolidated mill, reinforced concrete has been used. In Nevada, brick construction, for obvious reasons, is not used for mine-plants, but in the case of electrical installations for power-plant and sub-stations this method of construction is common.

The critical parts of a mine surface-plant are: the blacksmith-shop, boiler- and power-plant, change-quarters, woodshop, oil-storage, rope-house, and the structures about the shaft-mouth. With order, cleanliness, and a proper segregation of buildings, there is little chance for a fire, and yet carelessness on the part of any individual may be the cause of starting a fire, and consequently protection must be afforded by fire-plugs and hose-reels attached to the water-system. Usually the mine-plant is compactly arranged, and several plugs and hose-reels may serve all purposes. Small fire-extinguishers in each building are also considered necessary.

Underground mine-fires are serious, as in almost every case there is danger that fatalities may result, and the difficulty and danger of fighting such fires is great. In heavily-timbered mines where there is little or no water, the possibility of a small fire spreading throughout a mine is always present. Fortunately, dry mines usually do not have large areas of heavy ground, and heavily-timbered mines are often wet mines.

The causes of fires in metalliferous mines are:

The presence of combustible materials, such as timber, oils, waste.

Carelessness with candles, lamps, and smoking.

Blasting; remnants of smoldering fuse.

Overheated bearings in machinery.

Short-circuiting and overheating of electric wires.

Spontaneous combustion.

Rapid progress has been made in the development of methods of mining "without timber," and many methods involving a small proportion of timber, as compared with that required by the "square set" system, are in use. Even though we may largely eliminate timbered stopes or, by filling, practically eliminate the fire-risk from them, we still have the timbered drifts, stations, shafts, pump-stations, and winzes. We could almost completely eliminate the fire-risk from these by the use of steel and masonry, but this is practicable only in a few cases, and the mines of the West will undoubtedly utilize timber for many years to come. Underground, a relatively large amount of combustible material must be contended with. The critical places are the shaft-mouth, the shaft, the stations, the drifts, and the winzes. The critical condition is where the timber is dry and comparatively little water occurs. Where water is encountered the fire-risk is lessened. Systematic elimination of combustible material should be the first thought of the engineer. The proper protection from fire where combustible material must be used is the next consideration.

Carelessness with candles may be eliminated by the introduction of .electric lighting, and this method of lighting is common in Western mines of any size. Where candles are used, proper receptacles at stations and in stopes should be provided and their use insisted upon. The use of these will go a long way towards eliminating this cause. The setting of lighted candles upon timbers should be prohibited, and the removal of all candles from working-places when miners are leaving should be required. Lamps should be sparingly used, and where possible these should be filled and trimmed outside of the mine. Oil, and particularly oil required in illumination, should not be stored in the mine. Where oil-lamps are used by the miners, some form of solid illuminant should be used. Smoking can be controlled by mine-regulations, and in a heavily timbered mine, or in and about a wooden surface-plant, it should be prohibited. Where possible, the development of a stable, steady-working crew of men is an important factor in preventing accidents of any kind. Good foremanship is essential to this end.

Blasting as a cause of mine-fires is, no doubt, of minor importance. I know of no authentic case where the flame of a blast has been responsible for setting timbers on fire. In the case of the Homestake fire a piece of smoldering fuse has been given as the cause. However this may be, it is necessary carefully to inspect timbered stopes after blasting. A fire originating from any cause during the interim between blasting and the arrival of the next shift may thus be discovered before it has gained any considerable headway.

Overheated bearings of machinery are an infrequent cause of fire. Underground ventilating- and pumping-machinery are the only forms of machinery which would be likely to cause trouble of this nature. Ring oil-bearings on motors and fans have, to a considerable extent, removed this source of danger, but frequent inspection of machinery should be made. Where fans are in use an inspection should be made at least twice a shift by the shift-boss. Ring oil-bearings should be frequently examined and kept filled, and at intervals the oil should be completely removed, and the bearings thoroughly cleaned. Machinery oil should be kept underground in quantities only sufficient for several shifts' use. Machinery, where possible, should be placed in untimbered chambers or, where support of some kind is necessary, masonry, steel, or some fire-proof material should be used. At Virginia City the pump-rooms are heavily timbered and in themselves contain sufficient timber to sustain a considerable fire. The practice is to whitewash these timbers, and to keep such rooms thoroughly clean. While this reduces the fire-risk, still the presence of so much combustible material, and some of it of an oil-soaked nature, must be considered as a risk, and precautions should be taken to minimize it. (See note 1.) Such chambers can be readily provided with hose-plugs and reels. Where machinery of any size is in operation, the presence of attendants is usual, and is an additional safeguard. Oily waste and waste of any kind used in and about underground machinery should have metal containers provided.

Electric wires and apparatus may have been the cause of some fires, but where their installation has been carefully looked after, and they are in the hands of experienced men, it is seldom that a fire can be directly traced to their use. (See note 1.) The proper making of connections, the use of fuses, and automatic circuit-breakers on all apparatus will prevent excessive loads coming upon lines, electric motors, and transformers. At Virginia City transformers are used at several places underground. These are placed in timbered stations, but this practice is open to question. Transformers should be placed in chambers free from timbers, and only material of a fire-proof nature should be permitted in the vicinity. In surface electrical work transformers are placed in fire-proof buildings, and out of contact with wood-work. Where transformers are in use underground, and in the vicinity of combustible material, buckets of sand should be placed where they can be used in extinguishing a fire.[1]

Spontaneous combustion is an infrequent occurrence, for the reason that underground conditions are seldom of a nature that would lead to this cause. Oily waste might, under extreme conditions, develop sufficient heat to ignite combustible material in its neighborhood, but it is seldom that this is present. Fires in mines containing heavily sulphureted ores are claimed by some writers to be due to the heat produced by great pressure. While this cause is not of great importance, a careful mine-manager will not overlook it.

II. Fire-Prevention.

The first line of defense in the prevention of fire is a proper set of mine-regulations covering the use of candles, lamps, oils, and other combustibles used underground; the second is the enforcement of these regulations. Without discipline mine-regulations are of little avail. The third line of defense is the practice of a fire-drill at frequent intervals. This practice should include drill in the use of fire-fighting apparatus, the training of a suitable fire-fighting squad, and the accustoming of the men to answer an emergency fire-call, so that a possible panic among the men on the alarm of fire may be avoided. The drill should be segregated into the drill of the fire-fighting squad at least once a month, and the drill of the whole mine-force in answering a fire-call at least once in three months. The fourth line of defense is the use of watchmen, whose business it should be to inspect the mine-workings after a shift has departed or at frequent intervals when the mine is shut down. These men serve to check up careless miners and prevent a small fire from spreading.

Facilities for fighting incipient fires should be provided, and placed at readily accessible points in the vicinity of the places where there is any considerable amount of combustible material. These places would be at shaft-stations, the sill-floors of timbered stopes, timbered winzes, and shaft-collars. Fire-extinguishers of a simple type would be the means provided. Water-pipe line should be laid to large timbered stopes, and hose-connections provided. Hose-reels should be placed at the critical points. The whole system should be standardized so that hose, couplings, etc., could be transferred, and used in any part of the mine. At the surface a reserve supply of hose should be provided. A monthly inspection of fire-fighting appliances should be provided for.

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[1] The Factor of Safety in Mine Electrical Installations, *Technical Paper No.* 19, *U. S. Bureau of Mines* (1912).

Steel fire-doors, or wooden doors protected by tin sheets, set in concrete bulkheads, should be provided in cross-cuts and drifts at such points as would enable the spread of a fire starting in a stope to be checked. These would only be used in the event of a considerable fire. Such doors must be constructed so as to admit of opening from either side. In important tunnels of any great length and where timber is used several fire-doors might well be placed so as to divide the length into sections. In lieu of fire-doors a length of 100 ft. of the tunnel could be supported by masonry instead of timber, and this would localize a fire. In tunnel-fires fire-doors cannot always be reached, and the conditions may be such that temporary bulkheads cannot be constructed. In such cases the masonry zone might prevent the fire from spreading through the entire length of the tunnel. In railroad tunnel-work, where, from financial conditions, timber must be used instead of masonry, masonry zones might well be used. The recent fire in the Chilcoot tunnel of the Western Pacific railroad is a case in point. A main working-shaft in a mine would admit of fire-localization in the same way. In place of masonry, steel tunnel-sets or shaft-sets could be used. While perhaps general rules for the placing of fire-stops and doors could be formulated, the conditions at each mine would have to be studied and the locations of these safeguards determined in such manner as to best meet those conditions.

O. F. Heizer has informed me that at the Seven Troughs Coalition mine, Seven Troughs, Nev., hinged wooden doors, protected by $\frac{3}{16}$-in. steel sheets, are placed at the second set below the collar of the incline shaft (75° incline). These doors are held by trickers controlled by a lever. Slots are cut so that interference with the hoisting-cable is avoided. Ten sacks of sand are stored close by the shaft. In the event of a fire on the surface the surface-men have instructions to throw the doors and place the sand over them. He informs me that this device worked very well on one occasion when a fire took place in the surface-plant. He also informs me that at the Nevada Hills mine, Fairview, two steel sheets are arranged at the mouth of the shaft so that they may be slid over the opening of the compartment by throwing a lever. No special rollers are used, the sheets simply sliding on angle-irons.

To one familiar with conditions in Western mines, it is a matter of surprise that advantage has not been taken of the automatic sprinkler, which is in use for the protection of warehouses, factories, public buildings, and the like. I know of no instances where this system is used underground, and only in a few instances, notably in Montana, have they been used in metallurgical plants. The system as applied to buildings consists of a network of pipe-lines supplied by a pressure-tank. The pipes are so distributed as to admit of a sprinkler-head being placed in the center of each 10-ft. square. The sprinkler-heads are placed close to the ceiling. Each head is provided with an opening which is closed by a non-corrosive button. The button is held in place by a two-piece metal strip. The pieces of the strip are held in place by a soft solder which has a melting-point sufficiently low to be speedily reached by any fire in the vicinity. With the melting of the solder the pieces fall apart, the water-pressure forces the button out and the water spurts out against a spreader which throws the spray over a considerable area. A melting-point of 155° F. is used in the well-known Grinnell automatic sprinkler. The complete installation of an automatic sprinkler-system in a mine, while not necessarily impracticable, would in most cases be unnecessary. As has been mentioned, the critical places are the shafts and shaft-stations where the timbers are dry. Shaft and stations might well be protected by such a system. Timbered pump- or machinery-stations, on account of the value of their contents and their importance to the mine, could also be protected in this way.

The installation of an automatic sprinkler system in a shaft is represented in Fig. 1. Two main points in the design of

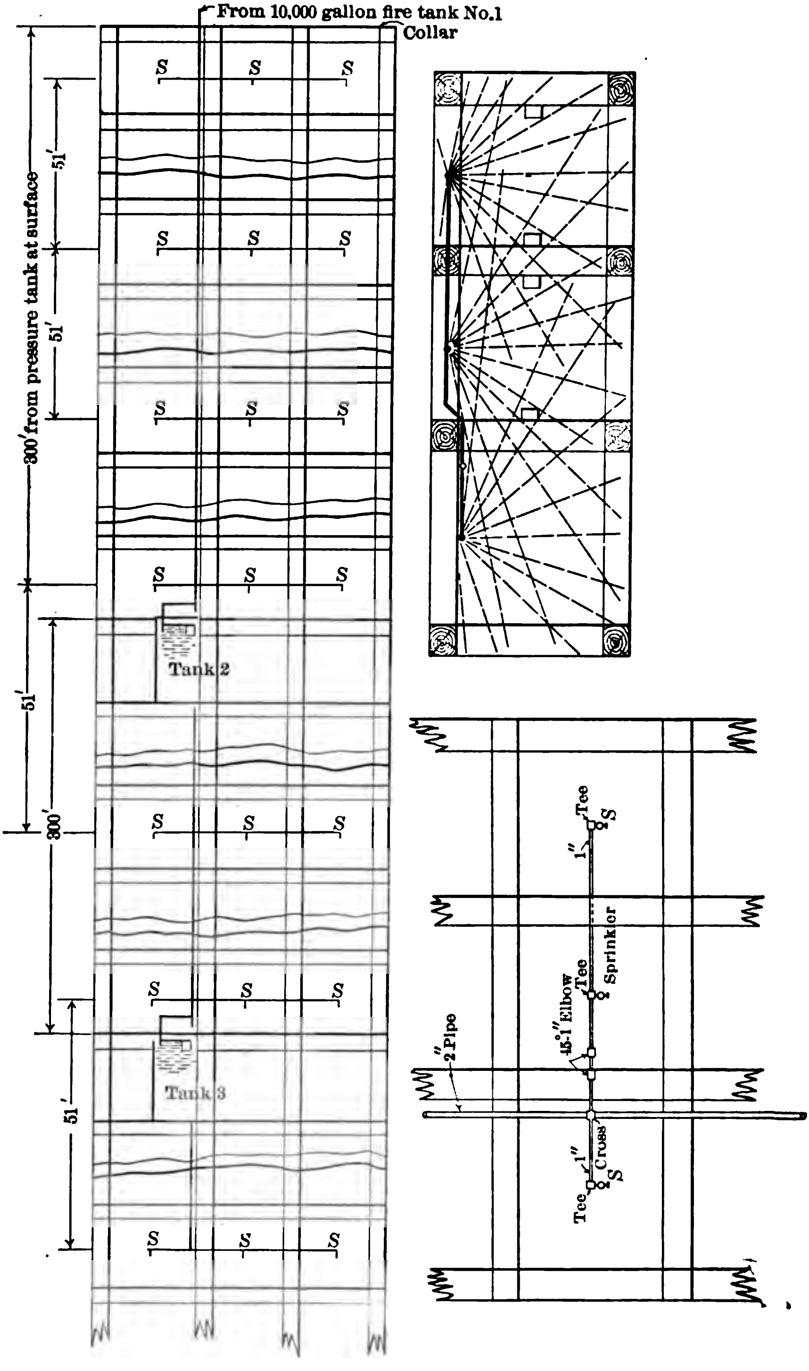
From 10,000 gallon fire tank No.1
Collar
S
51'
300' from pressure tank at surface
Tank 2
Tank 3
300'
Tee
1"
Sprinkler
45° 1" Elbow
2" Pipe
Cross

FIG. 1.—AUTOMATIC SPRINKLER INSTALLATION FOR A MINE-SHAFT.

such a system need consideration: one is the question of water-pressure; the other is the use of protective coating upon the pipe so that scale and rust cannot form and clog the sprinkler-heads. In a deep shaft it is doubtful whether a continuous pipe-line could be employed without the use of extra-heavy pipe and fittings. By placing pressure-tanks at intervals of from 300 to 500 ft., ordinary or "extra-strong" pipe and fittings could be used. The intermediate tanks could be supplied from the pipe-line above by means of valves operated by float. The use of galvanized pipe and fittings would eliminate ordinary troubles of corrosion.

In each compartment of the shaft, at intervals, sprinkler-heads, point downward, would be placed. In order to be out of the way these would be placed back against the lagging, but this position would not prevent their effective operation. A three-compartment shaft would be protected by making the intervals between sets of sprinklers 50 feet.

The cost of such a system is nominal compared to the amount of damage a shaft-fire might cause. I have estimated the cost of pipes, sprinklers, and pressure-tanks (every 300 ft.) for a shaft 1,000 ft. deep to approximate $500, or $0.50 per foot. In Fig. 1 a 2-in. pipe is assumed as sufficient. In the cost of the system should be included a fire-tank on the surface. Shaft-stations would be protected by extensions of the pipe-system along the center-line of the station and the spacing of sprinklers every 10 feet.

The advantage of such a system is its automatic operation. A fire arising in an obscure portion of the shaft would be taken care of and extinguished before it could spread. The shaft, the main exit of a mine, could thus be always protected and maintained in a workable condition. The possibility of saving life in the case of a fire would be greatly enhanced if shafts could without question be kept open.

By extending the sprinkler-system along each drift for 50 or 100 ft. a fire could be prevented from spreading to the shaft.

An automatic system to be satisfactory should be inspected at frequent intervals and such a system, carefully installed, would not require an overall inspection more than once in three months.

A telephone-system is an indispensable part of the equipment of a large mine. Not only is it necessary to install telephones at stations, but important winzes and stopes also should be provided with this appliance. The prompt warning of the men may be the means of preventing loss of life. This could be done by telephone or by the use of flash-signals where incandescent lamps are used. In Virginia City an "all out of the mine" signal is in use, and the electric lamps by a given number of flashes convey this signal.

Fire-fighting helmets are now considered necessary at all large mines, and the training of men in their use should be a part of the fire-drill. Oxygen-helmets also should be provided for possible use in rescue-work as well as for the attack of smoldering fires which would produce such an amount of smoke as to prevent near approach. So well has the subject of the construction and use of the oxygen-helmet been discussed that further comment is unnecessary here.[2]

All underground air-lines should be provided with connections at stations, winzes, and stopes. These connections should be maintained in working-order at all times. In the Belmont fire a connection on the air-line at the 1100 station would have been the means of saving life. Where a water-pipe line is not in use in a working-shaft, connections should be made at the surface, so that the air-line could be used for purposes of bringing water to a fire. It is preferable to have two lines of pipe in a shaft, one for water and one for compressed air.

III. Fighting Mine-Fires.

The first essential in fighting a mine-fire is to get all of the men out of the mine. When this has been accomplished, a plan of action can be decided upon and carried out under competent direction. The usual steps may be stated as: bulkheading, with the object of localizing the fire; laying of hose and the bringing of a water-supply to the scene of the fire.

The fire-fighting squad necessarily works upon the incoming-air side of a fire unless equipped with smoke- or oxygen-helmets. By carrying air-lines along with hose-lines, fire-fighting squads have been enabled to approach close enough to a fire from the "lee side" to do effective work. It requires courage and daring on the part of the fire-squad to perform work of this kind, but instances are not uncommon where stubborn fights of this kind have been made.

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[2] The Use and Care of Mine-Rescue Breathing Apparatus, *Miners' Circular No. 4, U. S. Bureau of Mines* (1911).

Where it is impossible to approach the fire close enough to fight it with water, two methods may be used: one is the bulkheading of the fire on both sides and the closing of all winzes leading from the fire-zone; the other is to seal the mine and fill the workings with a gas which will prevent combustion. In the former method the fire is left to smother out, and this may take considerable time. The availability of the oxygen-helmet renders it possible to construct bulkheads where it would have been practically impossible without the use of this appliance. In fighting a fire by the second method, steam, sulphur dioxide, and carbon dioxide have been proposed as gases suitable for the purpose. Steam is the agent most used. If a supply of sulphur could be speedily obtained, it might be possible to use this reagent in temporary burners arranged so as to discharge the gases into the intake air-ways. Snelling[3] has given details of the method. Carbon dioxide is difficult to generate in sufficient quantity, and its use is almost out of the question save as it is generated by the fire itself. Where it is impossible to bulkhead a fire, and steam or other agent is out of the question, the flooding of the mine is the next expedient. If it is impracticable to flood the mine, the turning of water down the shafts after sealing all openings to the mine is then in order.

The great danger in all mine-fires is the rapid filling up of the workings with smoke and poisonous gases (CO). To one who is familiar with fires this is the most striking thing. The comparatively restricted workings of a mine fill up in a very short time on account of the air-currents, which, while normally moving sluggishly, under the increased temperature rapidly acquire velocity. The presence of fire-doors at intervals may be the means of preventing workings from being completely flooded with irrespirable gases. If it were possible to stop all air-currents in a mine by doors suitably placed, the fire and the gas could be prevented from spreading outside of a restricted zone.

As in the case of surface-fires, "being prepared" is the key to the situation. Mine-superintendents should carefully consider the possibilities of a fire, and make every preparation beforehand, even to laying out a method of procedure for fires occurring in different parts of the mine. The drafting of a plan of action, the provision of apparatus and means for carrying out this plan, as well as the drilling and training of the men who are to carry the plan into execution, will go a long way towards preventing confusion, delay, and loss of control at the fire-signal. The provision for marking the passages leading to shafts and exits should be carried out in all large mines. A careful study of the ventilating-currents in a mine and a consideration of the effect of a fire in changing their direction also form necessary parts of any fire-fighting plan. Ventilating-plans of the mine under varying conditions should be prepared, and their study made a part of the drill by the fire-fighting squad. The effect of turning a stream of water down a shaft upon the air-currents deserves mention. In most cases a stream of water turned down an upcast shaft has the effect of reversing the air-current. In the Giroux fire the upcast shaft which was on fire was provided with a water-pipe, pierced with holes, close to the collar of the shaft. An attendant at the surface (without authorization) turned the water into this pipe, and thus reversed the direction of the air, causing the shaft to act as a down-cast. The Alpha shaft, which was the down-cast, became an upcast, and the miners escaping by this shaft were killed by the gases.

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[3] *Trans.*, xxxix., 550 (1908).

IV. Legal Regulations.

An examination of the mining-laws of the Western States indicates no general tendency to comprehensively cover the subject of mine-fires. As an example, the regulations provided by the State Mine Inspector Law of Nevada may be cited. These regulations are grouped as follows:

Regulations Relating to Egress from Mines.

"Section 19.—All shafts shall be equipped with ladders, and shafts more than 200 feet in depth, inclined more than 45 degrees from the horizontal, equipped with hoisting machinery, shall be divided into at least two compartments; one compartment to be divided off and set aside for a ladderway. The ladders shall be sufficiently strong for the purpose demanded, and landings shall be constructed not more than 30 feet apart; said landings to be closely covered, except an opening large enough to permit the passage of a man. A landing shall be constructed in manway at all working levels."

"Section 20.—In every mine within this State, if more than 200 feet in depth, where a single shaft affords the only means of egress to persons employed underground, and the ladderway compartment is covered by a non-fireproof building, it shall be the duty of the operator of said mine to cause said ladderway to be securely bulkheaded, or a trap door placed over same at a point at least 25 feet below the collar of the shaft, and if a trap door is used, it must be kept closed, or so arranged that it can be closed from a point outside of the building by the releasing of a rope, and below this bulkhead or trap door, if the shaft is situated on a side hill, a drift shall be driven to the surface, and if the shaft containing said ladderway may be otherwise situated, this drift shall be driven on the level to a safe distance, but in no case less than 30 feet beyond the walls of the building covering the main shaft, and from such a point a raise shall be made to the surface. The said raise shall be equipped with a ladderway, and it, together with the drift connecting with the main shaft, shall be kept in good repair, and shall afford an easy exit in the event of fire."

"Section 21.—Whenever the exit or outlet from a mine is not in a direct or continuous course, signboards, plainly marked, showing the direction to be taken, must be placed at each departure from the continuous course."

"Section 28.—It shall be the duty of every operator to provide every tunnel or adit level, the mouth of which is covered by a house or building of any kind, with a door near the mouth of the same, that can be closed from the outside of the building by a pull wire or cable in the event of fire; inside of door a raise shall be run to connect with surface, thus affording a means of exit in the case of fire."

Regulations Relating to Structures over Shaft-Mouths.

"Section 27.—It shall be unlawful for the operator of any mine within the State to erect any structure over the shaft of any mine, except head-frames necessary for hoisting from said shaft or outlet, and the hatch or door necessary for closing such shaft or outlet; *provided, however*, it shall be lawful to erect a house of non-inflammable and fire-proof material over such shaft or adit to protect the men working at such point. In the case of existing houses covering mouths of shafts or adits, it shall be the duty of the superintendent of the mine to cause the immediate removal of all inflammable material stored therein, and it shall be the further duty of such superintendent to prohibit the storage of any inflammable material 30 feet from the exterior walls of any housing hereinafter built."

Regulations Relating to Inflammable Materials Used Underground and on Surface.

"Section 16.—All timber removed shall, as soon as practicable, be taken from the mine, and shall not be piled up and permitted to decay underground."

"Section 22.—Use of gasoline underground is forbidden."

Regulations Relating to Fire-Fighting and Control of Mine-Fires.

"Section 41.—At every mine in this State, employing forty or more men underground, there shall be kept on hand at all times, in good working condition, at least two smoke helmets of a design to be approved by the State Mining Inspector, and which helmets shall at all times be subject to his inspection. For every additional fifty men so employed an additional smoke helmet shall be provided."

These regulations are, at best, only fragmentary, but they indicate an effort to provide certain things that a mine-operator must do. Most mine-operators are willing to conform to any reasonable regulations, but until a more or less complete code is drawn up and incorporated in our State mining-laws, we must expect to find them somewhat backward in taking the initiative, except in those cases where either bitter experience or broad training has stimulated operators to take the subject up in detail.

V. Proposed Regulations.

With the object of inviting discussion, and of giving point to the generalizations in the foregoing, I have written the following regulations. The difficulty of providing for every emergency that may arise in a mine-fire, and of meeting the miscellaneous conditions that are present in Western metal-mines, is apparent, and in preparing these regulations I have endeavored to maintain a conservative rather than an extreme position.

1. *Egress from Mines.*

For mines deeper than 200 ft., and employing ten or more men underground, operators must observe the following:

1. Two outlets must be maintained in good condition at all times during the operation of the mine.

2. Where two or more shafts are in use, two of such shafts must be provided with ladder-ways in separate compartments, and such ladder-ways maintained in good condition during the operation of the mine.

3. Where ladder-way shafts are inclined at a greater angle than 45°, landings closely boarded, and with openings just sufficient to allow the passage of a man, must be provided at intervals not greater than 30 feet.

4. In mines operated through three or more working-shafts, where each shaft is provided with hoisting-machinery, a ladder-way may be provided in but one shaft.

5. Between levels at least one winze must be provided with a ladder-way, and the same maintained in proper condition where the level is in use for extraction of ore, or ventilation.

6. On each level the direction to shafts and winzes, used as exits in cases of emergency, must be clearly indicated by sign-boards.

2. *Mine Surface-Structures.*

1. None but fire-proof buildings are to be permitted over shaft or tunnel-mouth.

2. Where shaft-mouths are open, wooden head-frames and bins may be permitted.

3. Non-fire-proof buildings must not be placed nearer than 50 ft. to any shaft-mouth or tunnel-entrance.

4. Mine-plant buildings of non-fire-proof construction must be separated from each other by a space not less than 30 ft. wide.

5. In a mine surface-plant where non-fire-proof construction is employed, hoisting-machinery, boiler-plant, blacksmith- and machine-shop, timber-framing shop, change-house, and storage of supplies must be placed in separate buildings separated by a fire-space not less than 30 ft. wide.

3. *Inflammable Materials on Surface and Underground.*

1. Where fire-proof shaft- and tunnel-houses are in use, timber or other inflammable material in excess of sufficient for one shift's use must not be stored in such buildings.

2. Timber-yard or timber-storage sheds must be placed not less than 75 ft. from any mine-building.

3. Lubricating-oils and inflammable fluids must be stored in fire-proof buildings separated by a distance of not less than 75 ft. from other mine-buildings.

4. Metal containers must be provided for the storage of all waste used in wiping and cleaning machinery. They are to be provided for each machinery-room in the surface-plant, and for each group of machines underground.

5. Lubricating- and illuminating-oils in excess of a 24-hr. supply must not be stored underground or in surface-buildings other than the oil-storage building.

6. Gasoline and substances of like nature are not to be used underground.

7. Timber in excess of a 24-hr. supply is not to be stored underground.

8. Powder-drifts which are used for the temporary storage and handling of powder underground, must be cleared of all paper, empty boxes and rubbish, at least once each 24 hours.

9. Where timber is framed at one or more points in a mine, these places must be cleared of chips and rubbish, at least once each 24 hours.

4. *Surface and Underground Regulations.*

1. Where mine surface-structures are of non-fire-proof construction a sufficient water-supply must be provided for fire-fighting purposes. One fire-plug and hose-reel must be placed not less than 25 ft. from the shaft-mouth, and such other fire-plugs placed as, in the judgment of the State mine-inspector and mine-superintendent, shall be sufficient to quench any ordinary fire.

2. At shaft-house, in timber-framing building, power-plant, change-room, and such other parts of the surface-plant as the mine-inspector may decide, at least two fire-extinguishers of an approved type must be placed and maintained in proper working-order. They must be placed in a conspicuous and convenient place.

3. Smoking shall be prohibited in non-fire-proof surface-plants.

4. Where more than a nominal number of lamps using illuminating-oils are in use a separate lamp-house shall be provided and all filling, cleaning, and trimming done in this building.

5. Where water-pipes are not installed in shaft, connections must be provided with the surface water-system so that the compressed-air pipes may be used to bring water underground in the case of a fire.

6. Connections must be made with air-pipes at each station, whether the same is in active use or not. These connections must be such that air can be turned into the station.

7. Where candle illumination is used underground metal sconces must be provided at all timbered stations and stopes and miners required to use same.

8. The placing of lighted candles on timbers without proper protection is prohibited.

9. Smoking is prohibited in timbered mines.

10. At all timbered stations which are in active use and where water-supply and hose-lines are not provided, at least two fire-extinguishers of approved type shall be placed and maintained in working condition.

11. Where electric illumination or power is used underground or in surface-plant, line-installation and protection must be in accordance with the Electric Code of the National Board of Fire Underwriters.

12. Transformers, where used underground, must be placed in fire-proof chambers and, at each bank of transformers, sand-boxes must be placed and a supply of sand maintained.

13. In heavily-timbered stopes fire-inspection must be provided after each shift leaves and before the new shift comes on.

14. Air-tight doors shall be constructed in each level, where practicable, between upcast and down-cast shafts. Such doors should be preferably of fire-proof construction.

5. *Regulations for Fire-Fighting and Control of Mine-Fires.*

1. The mine-foreman, under the direction of the mine-superintendent, shall have charge of all fire-fighting operations.

2. The mine-foreman shall designate certain assistants to constitute a fire-fighting squad, and assign duties to such assistants. The names of such assistants shall be posted at shaft-mouths as the fire-fighting squad.

3. The mine-foreman shall conduct a general fire-drill at least once each three months and at that time examine, test, and report to the superintendent the condition of all fire-fighting apparatus, exits, and ladder-ways. This report shall be in writing, and shall receive the signature of the State mine-inspector on his next inspection-visit after the fire-drill.

4. In mines employing 50 men, at least two smoke-helmets of an approved type shall be maintained in proper working-condition at all times. For each 30 men in addition an additional smoke-helmet shall be installed and maintained in working-condition. The foreman shall instruct the fire-fighting squad in their use.

5. In mines employing 200 or more men underground, at least two oxygen-helmets shall be maintained in proper working-condition. The foreman shall designate certain men for instruction and practice in the use of such helmets.

5a. In mines employing 200 or more men underground, a "pulmoter" in proper working-condition must be provided. The foreman shall instruct the fire-fighting squad in its use.

6. A general signal to indicate a surface-fire and one for an underground fire shall be designated.

7. Where practicable, an "all out of the mine" signal shall be designated and used in emergency. This signal must be used only by persons to be designated by the superintendent.

8. Detailed instructions to surface and underground men as to what to do in the case of fire are to be posted at shaft-mouth and underground stations.

VI. CONCLUSION.

This paper is written in the hope that some discussion will result. The use of fire-proof construction, the comparative cost of such construction, methods of preventing the spread of, and of fighting, mine-fires, and mine-fire regulations are subjects upon which many of the members of the Institute can no doubt contribute much of importance.

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EXCHANGE
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MANGANESE

By

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MANGANESE

INTRODUCTION

This bulletin is issued for the purpose of stimulating prospecting and development of possible sources of manganese in Nevada.

In the rush to do the big things in the war, some of the smaller, but no less vital, things are possibly overlooked. We do not realize the importance of the little that we can do. For example, the supplying of some of those rare or uncommon metals, which in ordinary times would not be necessary, at this time may become a vital factor for the successful conduct of the war. At this time, more than at any other time in our history, we need to develop our own natural resources and import nothing which can be produced from within our own borders. This will release for other service ships which are so much needed at this time. Production from our own resources, taken up as a war emergency measure, may develop new lines of industry for times after the war.

NEED OF MANGANESE

Manganese is one of these metals. It is absolutely essential for the production of high-grade steel. A recent statement of Secretary Franklin K. Lane of the Interior Department is to the effect that 50,000 tons of shipping is now necessary to supply the demands of the steel industry of this country with manganese, imported from Brazil, and that, could this shipping be released, it would be capable of carrying 300,000 tons of food and material annually to Europe.

MANGANESE DEPOSITS

Manganese ores occur in many parts of the United States, and in times past have been exploited to a certain extent. The deposits, however, are all small as compared with certain foreign ones and, due to several factors, have not been developed more extensively. Some of these limiting conditions have been: location of the markets in the East resulting in the need of paying high freight rates in comparison with the total value of the ore, uncertainty of payments after shipment, influence of the presence of certain impurities on the value of the ore, and high grade of ore demanded. These conditions have been greatly altered, due to the demand for manganese since the war started.

We can group our manganese deposits in three general classes:

(1) High-grade manganese ore chiefly valuable for manganese;
(2) Manganese silver ores; and
(3) Manganese iron ores.

Most of the deposits in the United States are secondary and have originated by the concentration of manganese originally occurring in some other form, more widely distributed in adjoining rocks. In general, the deposits are of comparatively slight depth, often consist of lenses and pockets of good ore, but widely scattered over considerable territory, and therefore require careful study to determine their possibilities.

MANGANESE IN NEVADA

Nevada has not been formerly looked on as a promising State for manganese, but some good though small deposits have been found. At Golconda we have examples of the first class of deposits. Some very good ore has been found. These deposits have been described briefly by E. C. Harder.* They are believed to consist of deposits formed from waters issuing from surrounding sedimentary rocks, and occur interstratified with silicious and calcareous tufa in a bedded deposit. At Pioche we have examples of the third class of deposits. A recent estimate of the Geological Survey places the probable ore in two Pioche deposits at 550,000 tons and possible ore at 1,000,000 tons, carrying approximately 12% manganese, 34% iron, 13% silica, and less than 0.1% phosphorus. While this type of ore has up to the present time been used only to a limited extent, more use may be made of it in the near future.

In view of the fact that little attention has been paid to this metal in the past, the extent of the mineralized sections of the State, and its common association with silver deposits, it is not unlikely that there may be many good deposits found here in Nevada. Recently very encouraging reports have come of new discoveries in different parts of the State, especially from near Las Vegas, Ely, and Golconda. The latest reports from Las Vegas indicate there are being shipped 60 tons daily with hopes of increasing this soon to 200 tons. Reports from Ely state they are making daily shipments of 20 to 25 tons and with improved transportation can increase this amount. If shipments of 220 tons daily could be maintained, they would have considerable influence on the general situation. In round figures they would total 80,000 tons yearly, and, as the estimated amount imported last year has been placed at about 500,000 tons, it is readily seen what an appreciable effect the Nevada supply would have.

The Mackay School of Mines has recently received from a number of different localities in the State very good samples of manganese ore. Attention should be directed first to securing ores of shipping grade without preliminary treatment. Some concentrating tests have been made to improve the grade of some of the low-grade silica-bearing ores with promising results. The Mackay School of Mines proposes to make further tests on this type of ore during the summer.

MANGANESE MINERALS

While there are many manganese minerals, there are only a very few commercially valuable. A few simple tests will serve to identify them. The oxides all have a dark color and streak; when fused with borax give an amethystine-colored bead; when fused with soda and niter give a greenish-colored bead; treated with hydrochloric acid give off chlorine gas.

The following are the chief minerals with a brief description of each:

Pyrolusite.

This mineral is sometimes called "black oxide of manganese." Its composition is manganese dioxide containing 63.2% metallic manganese. It is a soft black mineral having a metallic to dull luster; usually soft enough to soil the fingers; occurs massive, compact, stalactitic, and as crusts; its powder is black and its color black to steel-gray; gives an amethystine-colored bead when fused with borax; is soluble in hydrochloric acid liberating chlorine. It occurs in this State in several localities: Las Vegas, Ely, Golconda, and near Schurz.

Psilomelane.

This mineral does not have a definite composition, but the content of manganese is usually high, not, however, as high as pyrolusite. In color it resembles pyrolusite, but is very much harder, being 4 to 5, while pyrolusite is 1 to 2.5; it is never crystallized; occurs as a smooth black massive mineral; it is infusible; generally yields water in a closed tube; gives reactions with hydrochloric acid and borax similar to pyrolusite. It is usually associated with pyrolusite, and in this State with rhodonite, as at Golconda.

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*See "References" at end of this pamphlet.

Braunite.

This mineral is a manganese oxide of the composition Mn_2O_3; hardness of 6 to 6.5; submetallic luster; brownish-black to steel-gray color; gives reactions similar to pyrolusite with borax and hydrochloric acid.

Manganite.

This mineral is a hydrated form of the oxide, containing, when pure, 62.4% manganese; occurs as long and short prismatic crystals; has submetallic luster; steel-gray to black color; reddish-brown to black streak; gives with borax and hydrochloride acid reactions similar to pyrolusite.

Rhodochrosite.

This mineral is a carbonate, containing, when pure, 61.7% manganese; color rose-pink to brownish-red and brown; occurs massive, compact, and granular; hardness, 3.5 to 4.5; is transparent to opaque; brittle; is infusible, but changes dark-colored under the blowpipe; gives amethystine-colored bead with borax; is soluble in warm hydrochloric acid with effervescence; shows cleavage parallel to the rhombohedron. It is found in this State at Austin.

Rhodonite.

This mineral is the manganese silicate. The pure mineral would be of no value as a commercial ore, due to the presence of silica. It is generally rose-red to brownish-red in color; hardness, 5.5 to 6.5; gives an amethystine bead with borax. It is found in this State near Golconda.

Wad.

This mineral is a mixture of manganese oxides, together with the oxides of some other metals, notably copper, lead, and cobalt; color dark-brown or black; varies in hardness from 1 to 6; gives with fluxes the same reactions as pyrolusite and also often will give tests for lead, copper, and cobalt.

COMMERCIAL ORES

There are several factors which determine commercial or shipping ore. These factors are influenced by the use to which the ore is to be put. For example, a different grade is desired for use in making dry batteries than for making of ferromanganese for use in steel. Following are in general the limiting conditions which the manganese ore must fulfil for the steel industry:

1. The content in metallic manganese must run over 38%, and a higher unit-value is paid on ores as the content of manganese rises. It is preferred that the content of manganese run over 40%.

2. The silica content of the ore should run less than 8%, although ore containing as high as 12% will be accepted by some buyers and up to 15% by imposing certain penalties. These penalties are referred to

later in this report. Silica is objectionable, due to its tendency to produce a large volume of slag and also to carry manganese into the slag when smelted.

3. Phosphorus is not eliminated in smelting manganese ore, and is therefore limited to a very small amount in commercial ore. In general, the ore must contain less than 0.20% phosphorus.

4. Ore to be used in making ferromanganese must contain less than 8% iron. This is necessary in order to produce an alloy running 80% manganese. The lower the iron the more desirable the ore.

Some of the samples sent to the laboratory have shown on analysis up to 3% tungsten as the trioxide. Inquiry has been made regarding its possible influence on the value of the ore. With one exception, the replies indicate that, while it is not detrimental, neither is it thought that any return could be made for the contained tungsten. One dealer stated the tungsten would detract from the value of the ore for his purpose.

As some of the Nevada ore has shown sulphur in the form of both sodium and calcium sulphates, inquiry has been made as to the allowable amount of sulphur, and this has been fixed by one dealer at from 1 to 2% and the ore still be of value in steel manufacture.

CHEMICAL ORE

For use in making dry batteries, glass, and in the enameling industry the highest grade ore is required. It is then called "chemical ore." This type of ore commands a slightly higher price than "metallurgical ore." It must contain high manganese, preferably about 50% metallic manganese, less than 1½% iron, and less than 0.01% copper. Some ore of this grade has been found in Nevada, but in general the western ores contain too much iron or copper for this classification.

MANGANESE IN STEEL

Manganese, to become useful for the steel industry, must first be produced in the form of an iron-manganese alloy. If this alloy contains under 20% manganese, it is known as spiegeleisen; if it contains between 20 and 80%, it is known as ferromanganese. The higher grade alloy is demanded by the steel industry, and up to the present time the demand has been satisfied. In the attempt to use the manganese iron ores which occur in large amounts in this country, the lower grade alloy may come into more extended use.

Speigeleisen is usually produced by smelting a manganese iron ore in the blast furnace. Lime is the principal flux. Silica is objectionable, owing to its tendency to produce a large volume of slag and at the same time carry away with it large amounts of manganese. Ferromanganese is produced by smelting a high-grade manganese ore in the blast furnace or in the electric furnace.

Manganese is used in steel for the following reasons:

First—To neutralize the harmful effects of sulphur by the formation of the less harmful sulphide of manganese.

Second—To remove oxygen from the steel and prevent thereby the formation of blowholes.

Third—To produce the special alloy steel known as manganese steel, used for implements or parts of machinery subject to great wear, as crushing surfaces of ore-crushers, parts of plows, rails for curves on street railways where subject to heavy use, and burglar-proof safes.

BUYERS OF MANGANESE ORE

In this State there is only one firm which will buy manganese ore—the Western Ore Purchasing Company of Reno. Other firms outside the State will purchase ores. In a recent bulletin issued by the United States Geological Survey a list of purchasers of manganese ore is given. This bulletin has been reprinted in the Engineering and Mining Journal of January 26, 1918. These firms will buy the following grades and classes:

(1) 40% manganese ore, less than 2% iron.
(2) 40% manganese ore, more than 2% iron.
(3) 15 to 40% manganese ore.
(4) 5 to 15% manganese ore.

Both of the classes 3 and 4 probably apply the usual restrictions on the per cent of silica and phosphorus given below.

SCHEDULE OF PRICES

To illustrate the present custom of purchasing and prices paid for manganese ores, it is necessary to give what is called a price schedule. The figures of any such price schedules are always subject to the ordinary weekly changes in the market prices. The latest quotations can be found in such weekly periodicals as the Engineering and Mining Journal and the Mining and Scientific Press.

The following is an approximate schedule of present prevailing prices for manganese ores ranging from 38 to 50% and above, in pure metallic manganese: From 90 cents to $1.10 per unit of pure manganese of 22.4 pounds, found in a long ton of 2,240 pounds. These quotations are given f.o.b. eastern Pennsylvania points. They are based on the analysis of a sample dried at 212°F. Allowance is to be made, when making settlement, for moisture in the ore, as determined by drying a sample at the given temperature.

The following figures will illustrate the application of this price schedule: A unit is the same as 1% metallic manganese, thus a manganese ore assaying 1% manganese would contain one unit of manganese and, since we weigh such ore by the long ton of 2,240 pounds, it would be 1% of 2,240, or 22.4 pounds, as given above. A 50% ore would be one which contained 50 units of manganese. The price paid for a 50% ore being $1.10 per unit would make the value of such an ore $55 per long ton. Since a sliding schedule is used, a 38% would be figured as follows: 38% manganese indicates 38 units of manganese and in this case each unit is worth the lower figure stated above, or 90 cents; the value of such an ore would be 90 cents times 38 or $34.20 per long ton. An ore assaying between 38 and 50% manganese will have a rate per unit ranging between 90 cents and $1.10, according to the per cent of manganese present. Ore above 50% manganese will bear the $1.10 rate.

Penalties: For each 1% silica in excess of 8% there will be a penalty assessed of 50 cents per gross ton. For each 0.01% of phosphorus in excess of 0.20% there will be a penalty assessed of 50 cents per gross ton.

Premium: For each 1% of silica under 8% there will be a premium paid of 50 cents per gross ton, provided the manganese content goes 38% or better.

Rejections: Ore containing more than 15% silica, or over 0.20%

phosphorus, or less than 38% manganese, is subject to refusal or rejection at the buyer's option.

It might be of interest to Nevada prospectors to know that the Western Ore Purchasing Company will sample and purchase manganese ores in less than carload lots, which will enable them to obtain money with which to develop their property without delay.

FREIGHT RATES

The following freight rates have been supplied by the Southern Pacific Company as in effect at this time, March 29, 1918. These rates are per ton of 2,000 pounds. It should be noted that manganese is usually purchased, however, on the long-ton basis of 2,240 pounds, and allowance should be made for this fact in estimating the value of ore in a given case:

Golconda to Hazen	Value $50, $1.45 per ton;	Value $100, $2.20 per ton
Reno to Hazen	Value $50. $0.60 per ton;	Value $100, $0.90 per ton
Schurz to Hazen	Value $50, $0.60 per ton;	Value $100, $0.90 per ton
Hazen to Pittsburg		No value stated, $11.00 per ton
Hazen to Chicago		No value stated, $9.00 per ton

EXAMINATION OF SAMPLES

Samples of supposed manganese ore will be examined and tested free at the Mackay School of Mines if the samples sent are from within Nevada and are taken by residents of this State.

The School will gladly furnish further information on this subject to any person desiring the same.

The School will also appreciate any information regarding manganese deposits in this State, names of shippers or possible shippers, and any local problems in connection with increasing present shipments.

REFERENCES

"Manganese Deposits of the United States with Sections on Foreign Deposits, Chemistry, and Uses" (U. S. Geological Survey Bulletin No. 427, by E. C. Harder) is the best and most concise reference on the subject up to 1910.

"The Mineral Industry," issued annually by McGraw-Hill & Co., and "The Mineral Resources," issued annually by the U. S. Geological Survey, will bring the subject up to date.

"Metallurgy of Iron and Steel," by Bradley Stoughton, formerly a Professor of Metallurgy in Columbia School of Mines, and now the Secretary of the American Institute of Mining Engineers, is a good reference on the use of manganese in steel.

"Prospecting for Manganese," by Henry V. Maxwell, is a short interesting article appearing in the Engineering and Mining Journal for February 9, 1918.

In the September (1917) Bulletin of the American Institute of Mining Engineering is found a review of the New York Section's War Meeting on Manganese. This account gives the best present review of the subject as influenced by war conditions.

Bulletins have already been issued along similar lines to this by the State Mineralogist of California, and the Colorado School of Mines.

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APR 6 1928

UNIVERSITY OF NEVADA BULLETIN

VOL. XXII FEBRUARY 15, 1928 No. 1

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A TABLE FOR THE IDENTIFICATION OF NEVADA'S COMMON MINERALS

With Notes on Their Occurrence and Use

PREPARED FOR

THE MACKAY SCHOOL OF MINES

AND

THE STATE MINING LABORATORY

BY

OLIVER R. GRAWE

PUBLISHED QUARTERLY BY THE UNIVERSITY OF NEVADA
RENO, NEVADA

Entered in the postoffice at Reno, Nevada, as second-class matter under Act of Congress, July 16, 1894. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized April 21, 1919.

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PREFACE

This bulletin has been prepared to give the public of Nevada a better knowledge of those minerals which occur in workable deposits in the State, or which occur in sufficient amounts to attract attention. The important physical properties of the common minerals have been tabulated to enable an untrained person to determine systematically an unknown mineral by means of a few simple tests. These tests are described and the common terms used in describing the physical properties of minerals are defined. It is hoped that this bulletin will be of service in stimulating interest in minerals, not only by enabling citizens to determine minerals for themselves but also by rendering mineral reports more intelligible.

IDENTIFICATION OF NEVADA'S COMMON MINERALS

THE COMPOSITION OF THE EARTH

Our earth appears to be a complex aggregate of material varying widely from place to place. A gold mine is discovered here, gypsum deposit there, while over most of the earth many kinds of barren rock occur. The heterogeneity is more apparent than real, however, for the chemist, searching with the utmost patience and skill, has found that all the visible parts of our earth, land, sea, and air, are made up of only about ninety-two elementary building materials. These he calls *elements* and for brevity designates each by a *symbol*. Out of these few substances thousands of combinations have been made in nature. In each *compound* certain elements are combined in definite proportions by weight which the chemist indicates briefly in a *formula*. Thus, he finds pure water to contain two units of hydrogen and only one of oxygen. This he indicates by the formula H_2O, but since the building unit of oxygen weighs sixteen times as much as one of hydrogen, water contains in actual weight eight times as much oxygen as hydrogen or it contains eight-ninths or 88.8% oxygen and only one-ninth or 11.2% hydrogen. A *mineral* is just such a chemical compound which has been formed by natural processes. Each mineral, therefore, when pure, will contain a certain per cent of each of its component elements. A few minerals are themselves elementary and hence the element is said to exist free in nature. Native gold and silver are examples. Other minerals are highly complex. Some minerals can be profitably mined even when the percentage of gangue or waste material is large, while other minerals are commercially useless if only small amounts of impurities are present. In general, nonmetallic deposits must be much richer and purer than metallic deposits. Rock which averages less than 0.001% gold, if occurring in workable quantity, can be considered gold ore, but a few per cent of quartz in dumortierite will render dumortierite useless as a porcelain-making mineral.

Analyses of all sorts of inorganic earth material, minerals, rocks, water, and air further indicate the simplicity of our earth, for of the ninety or more elements, twelve make up over ninety-nine per cent of the earth. F. W. Clarke (*The Data of Geochemistry*, U. S. Geol. Survey Bulletin 770, p. 36, 1924) gives the following average percentages of the elements in known terrestrial matter:

Element	*Symbol*	*Percentage*
Oxygen	O	49.20%
Silicon	Si	25.67
Aluminum	Al	7.50
Iron	Fe	4.71
Calcium	Ca	3.39
Sodium	Na	2.63
Potassium	K	2.40
Magnesium	Mg	1.93
Hydrogen	H	.87
Titanium	Ti	.58

Element	*Symbol*	*Percentage*
Chlorine	Cl	.19
Phosphorous	P	.11
Total		99.18
All other elements		.82

Among those elements which make up but 0.82% of the earth, the following occur in the common minerals of the State:

Element	*Symbol*	*Element*	*Symbol*
Antimony	Sb	Mercury	Hg
Arsenic	As	Molybdenum	Mo
Barium	Ba	Nitrogen	N
Bismuth	Bi	Platinum	Pt
Boron	B	Silver	Ag
Copper	Cu	Strontium	Sr
Carbon	C	Sulphur	S
Fluorine	F	Tellurium	Te
Gold	Au	Titanium	Ti
Lead	Pb	Tungsten	W
Manganese	Mn	Zinc	Zn

Surprising as it may seem, most of the materials used in everyday life are comparatively rare. Usually they occur in unrecognizably small amounts in the rocks of the earth, and it is only under unusual and especially favorable circumstances that these rarer elements have been concentrated in commercial quantities. Nevada has been greatly favored as a site for the concentration of so many different substances.

In the table accompanying this bulletin the percentage composition of the commercial constituent of each mineral is given. This percentage is based on pure material, and hence gives the greatest amount of the component substance that can be present. Usually the percentages will run much lower because of the presence of other minerals as impurities. No percentages are given for a mineral useful as the mineral itself.

CLASSIFICATION OF MINERALS

Minerals may be classified in a variety of ways. The basis of classification may be use, occurrence, or some particular property, but since minerals are chemicals and since the use, occurrence, and properties of a mineral are ultimately dependent on its constitution, the best basis of classification is chemical composition. On this basis minerals may be arranged in thirteen or more groups:

1. Elements (Uncombined, free)—
   Sulphur (S), Gold (Au), Silver (Ag), etc.
2. Oxides (Compounds of oxygen with other elements)—
   Quartz (SiO_2), Hematite (Fe_2O_3).
3. Sulfides (Compounds of sulphur with other elements)—
   Pyrite (FeS_2), Chalcopyrite ($CuFeS_2$).
4. Chlorides (Compounds of chlorine with other elements)—
   Halite (NaCl), Cerargyrite (AgCl).
5. Fluorides (Compounds of fluorine with other elements)—
   Fluorite (CaF_2).
6. Silicates (Compounds of silicon and oxygen with other elements)—
   Cyanite (Al_2SiO_5), Orthoclase ($KAlSi_3O_8$).

7. Carbonates (Compounds of carbon and oxygen in the ratio 1:3 with other elements)—
   Calcite ($CaCO_3$), Smithsonite ($ZnCO_3$).
8. Sulphates (Compounds of sulphur and oxygen in the ratio 1:4 with other elements)—
   Anhydrite ($CaSO_4$), Thenardite (Na_2SO_4).
9. Nitrates (Compounds of nitrogen and oxygen in the ratio 1:3 with other elements)—
   Niter (KNO_3).
10. Borates (Compounds of boron and oxygen with other elements)—
    Borax ($Na_2B_4O_7.10H_2O$).
11. Tungstates (Compounds of tungsten and oxygen in the ratio 1:4 with other elements)—
    Huebnerite ($MnWO_4$), Wolframite ($Fe.MnWO_4$).
12. Molybdates (Compounds of molybdenum and oxygen in the ratio 1:4 with other elements)—
    Wulfenite ($PbMoO_4$).
13. Phosphates (Compounds of phosphorous and oxygen in the ratio 1:4 with other elements)—
    Apatite [$3Ca_3(PO_4)_2.\ Ca(F, Cl)_2$].
14. Hydrates (Compounds containing chemically combined water—
    Borax ($Na_2B_4O_7.10H_2O$).

PROPERTIES OF MINERALS

Since minerals are chemical compounds they have definite physical and chemical properties and, when free to crystalize, assume definite forms bounded by plane surfaces. The chemical properties of minerals are determined by the behavior of the mineral toward other chemical substances called reagents. A study of these properties makes necessary special equipment and is outside the scope of the present bulletin.

PHYSICAL PROPERTIES OF MINERALS

The terms used in the description of the physical properties of minerals are those used to describe any object. The following list includes those most commonly noted:

Color

Some pure minerals are colorless or white while others have a definite color due to their chemical constitution. Very few minerals are pure, and often the true color is modified by the color of impurities such as stains, inclusions, or mixtures. Surface alteration may notably modify the color of a mineral as well as change its other properties. In fact, another mineral has been formed by the alteration process. Therefore, *in testing any mineral a fresh unaltered surface should be used.*

Luster

Color depends on the kind or quality of light which a mineral sends to the eye while luster describes the intensity or relative amount of the light which is sent. Luster thus indicates the efficiency of the mineral as a reflecting surface. Common terms used are: Adamantine; a very brilliant, diamond-like luster. Glassy or vitreous: luster of ordinary window glass. Silky; the sheen of silk or satin. Other self-explanatory terms used are pearly, waxy, dull, submetallic, metallic. Only those minerals are considered to have a metallic luster which are opaque in thin slivers and which have the sheen of a metal.

Streak

The color of the fine powder of a mineral is called its streak. The powder may be easily formed by stroking the mineral across a piece of unglazed white porcelain called a streak plate. The unglazed edge of a piece of broken china or porcelain plate may be used as a substance on which to streak the mineral. Other ways of obtaining the streak are scratching the mineral with a knife or powdering the mineral with a hammer. In the latter procedure, however, care must be taken not to contaminate the streak by material worn off the hammer.

All colorless and white minerals have white streaks. Usually the color of the streak is a tint of the mineral color but occasionally the two are quite different. When this is true the color of the streak becomes very important in the identification of the mineral. Impure minerals will give impure streaks. This fact should be kept in mind when identifying minerals.

Hardness

The hardness of a mineral is a measure of its resistance to being scratched. In no way is it a measure of its resistance to a blow from a hammer, as quite commonly supposed. Arbitrary numbers have been assigned to designate the hardness of certain common minerals so that others might be compared with them. This scale of hardness is known as Moh's Scale. In it talc is taken as the softest mineral and is said to have a hardness of 1. Diamond is the hardest known mineral and is designated 10. Eight other common minerals are arranged in order between these two. Any mineral having a hardness between two minerals in the scale is given a hardness number half way between as 2.5. The numbers only show the order of hardness and in no way indicate the absolute relative hardness. Thus, gypsum is not twice as hard as talc. It is said that there is as much difference in hardness between diamond and corundum as there is between corundum and talc.

MOH'S HARDNESS SCALE

Mineral	*H.*
Talc	1
Gypsum	2
Calcite	3
Fluorite	4
Apatite	5
Feldspar	6
Quartz	7
Topaz	8
Corundum	9
Diamond	10

For all ordinary work it is only necessary to know that:

A finger nail has a hardness of about 2.5.
A copper coin has a hardness of about 3.
Window glass has a hardness of about 5.5.
A knife blade or file has a hardness of about 5.5.

Therefore, a mineral with a hardness of 1 can be scratched by all the above implements. One with a hardness of 4 cannot be scratched by the finger nail but can be scratched easily by a knife. It will easily scratch a copper coin but will not cut a piece of glass. In determining hardness, use a fresh, unaltered surface and, in addition, be sure that a scratch is made and that not just a trail of powder is left behind. Do not stroke one mineral in a scratch made by another. Granular minerals can be pulled apart in determining hardness but it is the hardness of the individual grains that is to be determined. Hardness like other properties may vary with crystallographic direction. Usually this difference is not great but in the case of cyanite, for example, the hardness is only 4 parallel to the direction of elongation of the mineral and 7 at right angles thereto.

Specific Gravity

The specific gravity of a mineral is an expression of the weight of a mineral compared to the weight of an equal volume of water. Minerals which have a specific gravity of 2.7 have about an average heft. They weigh 2 7/10 times as much as an equal volume of water. Those which have a specific gravity of about 2 are noticeably light, and those with a specific gravity above 3.5 are noticeably heavy. In comparing the specific gravity of two minerals, choose pieces of as near the same size as possible so that equal volumes are compared.

Structure

When minerals form, the particles arrange themselves in various ways which are usually described by familiar terms. The following terms have been used:

Crystalline: a structure due to the orderly arrangement of atoms throughout the whole mass. A property not easily recognized unless definite crystals are present. Most minerals are crystalline.

Amorphous: not crystalline, without crystal form or orderly internal atomic arrangement.

Acicular: slender, needle-like growth of crystals.

Radiating: crystals arranged about a common center like the spokes of a wheel about the hub.

Dendritic: crystals, often minute, have produced a tree-like branching structure.

Filiform: in form of thin wires or hairs.

Granular: a crystal aggregate of fine or coarse individuals held like the grains in lump sugar.

Drusy: a crystalline encrustation on a surface in which the surface becomes coated by a layer of small crystals.

Botryoidal: a semiglobular kind of structure giving a surface which resembles that of a bunch of grapes cut through the middle.

Reniform: a structure with a surface much like that of a kidney.

Foliated: a thin leaf or book-like structure.

Micaceous: a platy structure in which the mineral can be split into exceedingly thin sheets.

Lamellar: consisting of plates of appreciable thickness.

Stalactitic: icicle-like aggregates.

Concentric: onion-like structure composed of layers with a common center.

Concretionary: consisting of rounded particles.

Oolitic: a concretionary structure in which the rounded particles are small, like bird shot.

Pisolitic: concretionary particles about the size of a pea.

Nodular: the particles are large, rounded and irregular in shape.

Tabular: broad flat surfaces.

Compact: a uniform aggregate of minute particles.

Massive: a mineral composed of compact material and not showing any definite form is said to have a massive structure.

Disseminated: the mineral is rather uniformly distributed through the rock in which it occurs.

Other structural terms used in the table are self-explanatory.

Form

When a mineral is free to crystallize while it is forming it usually assumes some definite shape called a crystal. Such shapes are:

Cube: six square faces at right angles to one another.

Rhombohedron: an equal six-sided form in which the sides have parallel but not right-angled edges. Such a form as is produced when a cube is distorted by pushing at one of the corners.

Prism: faces usually rectangular, with parallel edges.

Pyramid: a crystal form with triangular faces which meet in a point; a peak-like form.

Octahedron: an eight-sided figure with equal triangular faces.

Tetrahedron: a four-sided form with equal triangular faces.

Dodecahedron: a twelve-sided figure bounded by diamond-shaped faces or by five-sided faces as in the case of the *pyritohedron*.

It is only under very favorable circumstances that a mineral will form good, easily recognizable crystals. Those inexperienced in mineral determination will find this property of little use.

Cleavage

Some minerals tend to break along smooth, flat surfaces. This property is called cleavage. The planes so produced glisten in the light and even though the mineral may be an aggregate, each grain will show its cleavage faces by the light it reflects to the observer's eye. Cleavage is described according to the cleavage form produced. For example, a mineral with cubic cleavage, like galena, can be broken into small cubes. Usually it is only necessary to determine the number of different plane surfaces produced when the mineral is broken and to note the perfection of the surface and the ease with which it may be obtained. Some minerals, like galena, break equally well in three directions; others, like mica, are only cleavable parallel to one direction.

Fracture

The broken surface which is not a flat cleavage surface is called a fracture surface. Minerals which have poor cleavage yield good fracture surfaces. Fracture is always determined in a direction in which there is no cleavage. The kinds of fracture are:

Even: a smooth but not flat surface.

Uneven: irregular surface without any special character.

Hackly: many irregular sharp edges in the broken surface.

Conchoidal: a shell-like surface with curved and often concentrically ribbed markings.

Splintery: a wood-like fracture.

Earthy: broken surface like that of clay or chalk.

Tenacity

The tenacity of a mineral is that property which depends upon the cohesion of the particles, or the power they have to hold together. Various terms are used to describe this property:

Brittle: easily shattered by a hammer blow.

Malleable: can be hammered into thin sheets.

Ductile: can be drawn out into a wire.

Friable: granular minerals which can be crushed or worn off in the hand.

Sectile: can be cut into thin shavings by a knife.

Flexible: thin sheets of the mineral can be bent back and forth without breaking.

Elastic: thin sheets of the mineral can be bent within the so-called elastic limit but will not remain bent after the distorting force is removed.

Tough: resists shattering by hammer blows. Opposite to brittle.

Diaphaneity

This property depends on the ability of the mineral to allow light to pass through it.

A transparent mineral is one through which printing can be seen.

A translucent mineral allows light to come through but this is too diffuse to permit clear vision through the mineral.

An opaque mineral will not transmit light even when thin. Thin splinters of such a mineral will not allow light to come through their thin edges.

Special Properties

Some minerals have other characteristics in addition to those already described. Under this heading are included solubility in water, taste, odor, feel, and magnetism. Only soluble minerals have a definite taste. A mineral may best be tasted by breaking off a small fragment, tasting that and then removing it from the mouth. Odor is best obtained if the mineral is first moistened by blowing the breath upon it before smelling of it. Some minerals like the metals and hard rock minerals, feel cold, others harsh, greasy, or soapy when rubbed between the fingers. Magnetism can be tested best by suspending a horseshoe magnet on a finger and noting the presence or absence of attraction when the mineral is brought up to the magnet. A few minerals show a play of colors called iridescence when turned in the light. Such phenomenon is seen when oil is dropped on water. When a mineral is doubly refracting, printing will be blurred or seen double when viewed through it. This only can be tried on transparent minerals. A striated mineral will show fine parallel lines or scratches on its surface.

Minerals illustrating the foregoing properties may be found by referring to the accompanying table.

MINERAL ASSOCIATIONS

Most minerals are stable only under certain conditions and when they are removed from this environment they undergo change. Therefore, minerals are indicators of the formation in which they occur. Some are stable when deeply buried, others are stable at the surface. Some occur in hard crystalline rocks, others only in surface deposits. Those minerals are found together which are produced by the same kind of processes or which are alike chemically. For example, galena and sphalerite, or pyrite and chalcopyrite are often found together because they are all sulphides and are produced in the same kind of way. Similarly, in the upper part of veins carbonates like malachite, azurite, and cerussite are found with such oxides as limonite, cuprite, and hematite. This is due to the fact that some of the original minerals have been altered by the carbon dioxide of the air while others have been affected more directly by the oxygen therein. The fact that minerals are often accompanied by their alteration products is a real aid in mineral identification. For example, chalcopyrite becomes coated by green malachite whereas pyrite which may be mistaken for chalcopyrite alters to brown limonite.

Minerals are not haphazardly distributed in the rocks but occur where they do because certain forces have acted. Hence they often indicate the forces which have produced them. They may indicate the nature of an ore deposit, may sometimes give information regarding the feasibility of sinking a shaft deeper, or of abandoning all hope and saving the expense. The one who best understands minerals will best be able to interpret the forces which have produced them.

THE DETERMINATION OF MINERALS

Minerals may be identified on the basis of their characteristics. When all other methods fail it is usually possible to determine a mineral by a complete chemical analysis but, since this is expensive and involves much labor and skill, it is usually employed only as a last resort. Fortunately, most of the common minerals have distinguishing physical properties by which they can readily be identified. Such a determination may then be checked, if necessary, by chemical tests for the substances the mineral contains.

In the accompanying table the minerals are arranged systematically according to their physical properties. Streak is the first property to be determined when this table is used. This is easily obtained by one of the methods already described. The streaks are arranged from the pale colors to the dark ones and minerals having the same colored streak are listed in order of increasing hardness. When more than one mineral has been included for a given hardness the list is in the order of increasing specific gravity. These three properties in general will narrow the choice to a few minerals which can then be discriminated on the basis of other properties. Occasionally the mineral association will aid in the choice and should not be overlooked. In no case should a mineral determination be based on just one or two tests and in every case a mineral should be determined without preconceived ideas as to what it is. If one wishes confirmatory chemical tests, textbooks on chemical mineralogy or blowpipe analysis may be consulted. A list of these will be furnished by the Mackay School of Mines on request.

The chart includes only the more common minerals of the State and the most common of these are printed in capital letters. When there is any doubt as to the identity of a mineral it is best to call it the name of the most common mineral it most closely resembles. The chance of this identification being right is greater than any other.

The State Mining Laboratory is maintained at the Mackay School of Mines to assist in the exploitation of the minerals of the State. Within the limits of the law, it will mail a mineral and assay report to any resident of Nevada who submits for analysis samples obtained within the State. Those who use this privilege will find this bulletin useful in identifying minerals in a sample which has been analyzed by the State Mining Laboratory. Since the Laboratory does not return samples, the sender will find it convenient to keep duplicate samples to compare with this bulletin and the report when it is received.

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TYPOGRAPHICAL
UNION LABEL
WASHOE

UNIVERSITY OF NEVADA BULLETIN

Vol. XXII MARCH 15, 1928 No. 2

A BULLETIN

BY

THE MACKAY SCHOOL OF MINES STAFF

ON THE MINERAL

DUMORTIERITE

PUBLISHED QUARTERLY BY THE UNIVERSITY OF NEVADA
RENO, NEVADA

Entered in the post office at Reno, Nevada, as second-class matter under Act of Congress, July 16, 1894. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized April 29, 1919.

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1^{59}

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FOREWORD

This is the first of a series of bulletins to be issued by the Mackay School of Mines on live subjects of interest to the industry.

The bulletin is made up of articles by members of the school staff, each member contributing the portion which naturally falls in his department.

Our acknowledgment and thanks are due the following persons for information and specimens supplied:

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JOHN A. FULTON,
Director.

THE MINERALOGY OF DUMORTIERITE

By O. R. Grawe
Instructor in Mineralogy, Mackay School of Mines

HISTORY AND OCCURRENCE

The history of dumortierite as a distinct mineral species dates back to November 13, 1879, when Ferdinand Gonnard (16)[1] checking up some of the mineralogic and petrographic observations of A. Drian in the vicinity of Lyon, France, chanced to see a beautiful fibrous blue mineral adhering to the feldspar of one of the gneissic blocks among a pile of stones used in repairing the road near Beaunan. At the time he thought that the mineral might be cyanite and made no attempt to collect more material or to trace it to its source. Later he submitted his small amount of material to Bertrand for determination. The intense pleochroism and other optical properties convinced Bertrand that this mineral was unlike any known and in his note of 1880 (1) he pronounced it a new species. This is the first published article on dumortierite. With the encouragement of having found something new, Gonnard (16) returned to the original locality and collected material which furnished the basis of his paper of 1881 in which he named the mineral dumortierite in honor of the Lyon palaeontologist, Eugène Dumortier. Gonnard's article was accompanied by Damour's (6) giving a chemical analysis and formula for the new mineral.

In the years which have followed the discovery of dumortierite, the mineral has been observed in many localities of world-wide distribution. It usually occurs in minor amounts as acicular, often radiating or fanlike inclusions in minerals contained in pegmatite or quartz veins which cut acidic aluminous rocks and it occasionally occurs in separate aggregates and in larger quantities. At Beaunan, southwest of Lyon, France, Gonnard found it in a pegmatite which cuts cordierite gneiss and later found similar occurrences near Oullins (17) and along the road to Francheville near Brignais (18). Websky (49) was the first to report dumortierite outside of France. He found it in pegmatite with corundum in the Riesengebirge of German Silesia, at Wolfshau, west of Schmiedeberg. Similar occurrences have been observed in the gneiss near Weitenegg (19) and in Switzerland. From the southern margin of the Bergeller massif of the Swiss Alps, Hugi and Hirichi (21) have described an occurrence of dumortierite in a quartz, rich muscovite pegmatite, and Linck (30), much earlier, described a similar occurrence in the pegmatite of the lower Val Donbastone in Upper Veltlin. Other southern European occurrences are located in Czecho-Slovakia. Rosler (40) has observed dumortierite in the kaolinized products of decay of a muscovite biotite granite at several places in Bohemia, namely, at Imligau near Chodeau, at Schobrowitz, near Karlsbad, and at Oberbris, near Pilsen. Kratochvíl (24) records another Bohemian locality, Pelhřimov, near Putimov, where the dumortierite occurs in an aplite dike traversing granite and gneiss and in which the small prismatic grains of dumortierite are accompanied by andalusite. In Moravia bluish green fibers and prismatic aggregates of dumortierite accompany sillimanite in small pegmatite veinlets which traverse a sillimanite biotite gneiss at Vymyslice, near Moravský, Krumlov (39).

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[1] These numbers refer to the numbered articles in the bibliography.

Northern as well as southern Europe contains minor amounts of dumortierite. It is a microscopic constituent of a pegmatite which cuts garnet mica gneiss and such basic rocks as peridotite, pyroxenite, gabbro, and others on the Kyshtymsk estate in the Uvildy Lake district of the Russian Urals (25). Inclusions of dumortierite in the cordierite gneiss of southern Norway have been described by Michael Lévy and Lacroix (32, 26) from the vicinity of Bamle, Tvedestrand, Kragerö, and Arendal. Mackie (33) recently has recorded the occurrence of the mineral in the gneiss, granite, and pegmatite of four localities in Aberdeenshire and Banffshire, Scotland, and in the granite of Cornwall, England.

Anfoka, near Soavina, 25 kilometers north of Ambalofinandrahana, Madagascar, is the only African locality in which dumortierite is known to occur. According to Lacroix (27), the mineral is disseminated in quartzite which is accompanied by other quartzites containing lazulite. In view of all other occurrences, one wonders if Lacroix's quartzite may not be veins of granular replacement quartz.

In the South American Continent dumortierite has been found in Argentina and in Brazil. It occurs as an accessory mineral in granite at Potrero, Province of Catamarca, Argentina (38), and as fibrous aggregates in pegmatites at Rio de Janeiro (12, 37). Riman (37) records two occurrences of dumortierite near Rio de Janeiro, one in the suburb of Copacabana where two pegmatite dikes intrude a garnet cordierite gneiss; the other at Ipanema in the south slope of the Morro de Cantagallo where six pegmatite dikes, four of which contain dumortierite, cut cordierite sillimanite gneiss. Ferraz and Roccati (12) more recently have recorded the occurrence of dumortierite in the diamond bearing sands at Diamentina, Riacho de Varras, Candonga, and Cachorra de Paraima.

North American dumortierite has been found in one locality in Canada, one in Mexico, and in several in the United States. In 1921 brief mention was made of the presence of dumortierite in the N½, Lot 31, 14th Concession of Ashby Township, near Bancroft, Ontario, where a pegmatite vein one foot wide intersects a gneiss (53). In a later paper Walker (48) described this occurrence more fully. The dumortierite is included in muscovite, quartz, and microcline and coats joints in the pegmatite itself. The Mexican dumortierite of the Sierra de Guadalcázar in the State of San Luis Potosi forms the basis of the papers by Wittich and Kratzert (51, 52). It is associated with topaz in quartz boulders which the authors believe to be derived from pegmatite veins cutting the granite laccolith at Realejo, four kilometers northwest of Guadalcázar, because the streams carrying the boulders have their source in this granite mass. The presence of dumortierite with such fluorine minerals as topaz and fluorite makes this occurrence very much like those in Brazil.

Seven of the United States contain dumortierite: Arizona, California, Colorado, Nevada, New Mexico, New York, and Washington. The intense blue color of the mineral at Harlem, New York, attracted the attention of mineral collectors early in the Nineteenth Century but, lacking petrographic microscopes, they classified it as the blue variety of tourmaline, indicolite. It is so recorded in Webster's (50) catalogue of the minerals of New York State, published in 1824, and was so called until 1887 when Riggs (36) had occasion to examine a specimen of this indicolite. His analysis showed that although the mineral contained boron, its composition was quite different from that of tourmaline. A subsequent hasty examination by Diller also showed that the mineral was not tourmaline but it was left for E. S. Dana (7) to suggest that the mineral might be identical with Gonnard's dumortierite. Subsequent analyses by Whitfield (9, 10) and further examinations and comparisons with the French material by Diller (9, 10) proved the correctness of Dana's suggestion. The New York mineral occurs as prismatic needles and fibrous radiating tuffs, included primarily in the feldspar, and sparingly scattered through a pegmatitic portion of a biotite gneiss. Chamberlain (4) wrote that as early as 1865 it was observed by S. C. H. Bailey at Kip's Bay, near the upper end of Riverside Park, many other localities within New York City, including those previously listed by Chamberlain (4) and Hovey (20), are given by Schaller (44).

Dumortierite specimens from Clip, Arizona, were described and analyzed by Diller and Whitfield (9, 10) in 1889. Later, material from this locality was analyzed by Ford (14, 15) and further studied by Schaller (43, 44, 45), who described the mineral as occurring only in loose boulders of quartz rock associated with cyanite, magnetite, and muscovite. Clip has passed out of existence. It is not to be found on modern maps of Arizona and no longer is it listed in the Postal Guide. Information regarding its location has been supplied by Dr. W. F. Foshag,[1] who writes that old atlases show the location of Clip to have been on the Colorado River, near the present camp of Cibola. The place also has been referred to as Clipper Gap. He continues: "This is very close to the landmark called Picacho Peak and the two dumortierite localities are probably identical. Rolled boulders are sent us from time to time from Ogilby and specimens of cyanite that are similar to the cyanite associated with the dumortierite are in our collections from the American Girl Mine about 10 miles north of Ogilby, and others from three miles north of Ogilby. There is perhaps a belt of dumortierite and cyanite rocks in this district." Specimens in the Mackay Museum also show a striking similarity between the Clip dumortierite and that from Imperial County, California, in the vicinity of Picacho Peak. It is likely that the boulders at Clip actually had their origin in California.

According to Dean G. M. Butler,[1] dumortierite occurs in two other localities in the State of Arizona. One is the Patagonia Mining District, 12 miles notheast of Nogales, the other is in the northern part of the State, not far south of Quartzite.

Barring the above explanation of the source of the Clip dumortierite, the California mineral was first mentioned by Ford (14, 15) as occurring in a quartz dike, 30-40 feet wide which cuts a biotite-granite a few miles east of Dehesa, San Diego County, California. According to Schaller (44) the upper part of this dike is a fine-grained, whitish, or grayish schistose quartz containing sillimanite, a little muscovite, and no dumortierite. Downward the dike loses its schistosity, becomes coarser and dumortierite appears. Both dumortierite and muscovite become more abundant with depth.

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[1] Personal communication to Director Fulton.

The University of California recently supplied us with a specimen of dumortierite obtained by Charles Anderson four miles northeast of Corona in Riverside County, and other California occurrences in Imperial County have been called to our attention by Dr. Jeffery and by Dean Butler,[1] who sent us a specimen obtained six miles northwest of Picacho Peak, but no geologic reports have been published concerning these deposits.

The only account of dumortierite in Colorado is that published by Findlay (13) in 1907. He found the mineral associated with corundum and sillimanite along Grape Creek, seven miles southwest of Canyon City, Fremont County, Colorado. The parent rock is a pegmatite dike 40–80 feet wide which cuts through an epidote schist.

At the headwaters of the North Fork of the Washougal River in Skamania County, Washington, small spherulites of fibrous dumortierite occur in a fine-grained mass of muscovite, andalusite, and quartz. Specimens from this locality were first described by Ford (14, 15) and later by Schaller (44). A similar occurrence of dumortierite in New Mexico has been noted by Schaller (45). A quartzose sericite rock in the Tres Hermanas mountains of Luna County, 12 miles northwest of Columbus, contains blue spherulites of dumortierite.

Dumortierite is known to occur at four places in Nevada. Jones (22) observed the pink variety in the sericite schists of the Rochester Mining District of Pershing County, but in his hasty examination mistook it for rubellite. Knopf (23) later called attention to this mistake and published the first account of dumortierite in the State. He described the dumortierite veinlets in the Triassic (Koipato) sericite schist on the west slope of Lincoln Hill in the Rochester District. This work was published in 1924. In the next year R. H. Rowland discovered that his claims in Pershing County, in the Humboldt mountains just north of the Rochester District, contained a large deposit of dumortierite. This deposit lies in Humboldt Queen Canyon (sometimes referred to as Limerick Canyon, which is really to the south), six miles east of Oreana. Rowland's claims were purchased by the Champion Porcelain Company of Detroit, Michigan (subsidiary of the Champion Spark Plug Company of Toledo, Ohio), in October, 1925, and development work was begun. The highest grade dumortierite has been shipped to the Porcelain Company's plant at Detroit, Michigan, and used in the manufacture of spark plug porcelain, thus making the Humboldt Queen deposit the only commercial occurrence of dumortierite in the world. Fairbanks (11) and Peck (35) have already described the mineralogical properties of this dumortierite and, since it is the primary purpose of this bulletin to discuss this deposit quite fully, there is no need of further discussion here.

Another known locality of dumortierite in Nevada is at the southern end of the Granite Range in Washoe County, approximately eight miles northwest of Gerlach. R. M. Oliver, who has recently visited the locality, describes the pink dumortierite as occurring in segregations in the granite associated with quartz and muscovite. The fourth locality in the State is Round Mountain in Nye County. The mineral is a beautiful sodalite blue and, according to H. S. Clinton,[1] it occurs in a quartz replacement within a granite mass. Neither of the latter deposits have been investigated and much work remains to be done.

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[1] Personal communications to Director Fulton.

MINERALOGICAL PROPERTIES

A. Crystallographic Properties

No very good crystals of dumortierite have been found. Practically all the crystal forms of the mineral have been determined by Schaller (44). His work is based on six incomplete prismatic specimens: two from Dehesa, California, one from Clip, Arizona, and three from New York City. Dumortierite is orthorhombic with the following axial ratios: 0.8897 : 1 : 0.6871.

The forms observed by Schaller are:

a. macro pinacoid (100)
b. brachy pinacoid (010)
m. Unit prism (110)
l. brachy prism (120)
g. macro prism (320)
n. macro prism (210)
d. macro dome (102)
v. macro dome (203)

Schaller detected several other forms but the faces were too minute to determine with certainty. Dumortierite crystals are often vertically striated on the prism faces due to repeated pseudohexagonal twinning according to the laws obeyed by cordierite and aragonite (44, 48). Further crystallographic data may be obtained from Schaller's publication.

B. Physical Properties

Color. Most frequently some kind of blue variously described as cobalt, azure, ultramarine, lilac, or sodalite-blue. Weathered surfaces of this blue variety are often nearly black. Notable exceptions to the most common color are: the pistacite green dumortierite of the Val Donbastone (30) and of Brazil (37), the lavender of Riverside County and of San Diego County, California (44) and Nevada (11, 23, 35), the rose of Nevada (11, 23, 35), and Madagascar (27). When heated for a few seconds above 800° C the mineral becomes permanently grayish or white (6, 3).

The cause of the color is dumortierite has been subject to some speculation. Damour (6) suggested that the color might be due to titanium. Schaller (44) failed to get a titanium test by the hydrogen peroxide method from blue Washington dumortierite free from rutile and titanite, whereas the California lavender dumortierite contains about 1.5% Ti_2O_3. From this it would seem that the blue dumortierite contains no titanium replacing aluminum, whereas the red does. Lacroix (27) does not agree with this, finding titanium in both the rose and lilac dumortierite of Madagascar, but one does not know whether the titanium which gave the test occurred as rutile or titanite, or as a partial replacement of the aluminum. Peck (35) found practically no difference between the refractive indices of pink dumortierite and those of lavender and light blue crystals and thus ruled out Fairbanks's

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[1] Clinton, H. G., personal communication.

(11) suggestion that there might be some relationship between titanium content, color, and refractive index. As pointed out by Peck, the dumortierite usually contains inclusions of rutile which indicate that the dumortierite has absorbed its full amount of titanium, and hence it probably forms a part of the molecule of both the pink and blue varieties. This conclusion is further borne out by the fact that Peck has discovered some veinlets of dumortierite which are blue near the walls and pink at the center. Jones has found a similar gradation in the Nevada dumortierite while Walker (48) observed that the centers of some dumortierite crystals have a defferent pleochroism from their exteriors. Peck suggested that perhaps the color may be due to the state of oxidation of the titanium. In blue dumortierite it may be present as Ti_2O_3 and replace a part of the alumina, in pink dumortierite it may be oxidized to TiO_2 and replace a part of the silica. As further pointed out by Peck, however, the color effects of iron, manganese, and small quantities of other elements must not be overlooked, and one must keep in mind that "the color of the mineral is a matter easier to speculate upon than to prove."

Streak. A light tint of the color, nearly white.

Luster. Vitreous to mat (dull).

Diaphaneity. Transparent to translucent on thin edges or in crystals, but massive material appears to be opaque.

Structure. Fanshaped radiating masses, fibrous, acicular, prismatic crystals, occurring in masses, in spherulitic aggregates and as inclusions.

Cleavage. Distinct parallel to macropinacoid (100). Indistinct parallel to prism (110). Indistinct parallel to brachy pinacoid (010).

Cleavage Angles—

$110 \wedge 110 = 124^\circ \pm (9, 10)$. $100 \wedge 110 = 152^\circ \pm (9, 10)$.

Fracture. At right angles to the c axis.

Parting. Imperfect parallel to basal pinacoid.

Hardness. 7.

Tenacity. Very tough in massive aggregates.

Specific Gravity. Maximum is 3.36. Average 3.30. Variations in recorded specific gravities are largely due to variations in purity of material.

Fusion Point. On being heated, dumortierite decomposes to mullite which fuses at 1810° C (3).

Dielectric Constants. Fairbanks (11) has determined the dielectric constants of Nevada dumortierite and two other aluminum silicates:

Dumortierite (violet) Nevada	17
Dumortierite (red) Nevada	17
Andalusite (bluish) California	8
Andalusite (bluish) Tyrol	12
Cyanite (blue) Nevada	7–9

X – infinite. Error ± 1

C. Optical Properties

Interference figure, Biaxial.
Optic sign, Negative.
Index of refraction—

Investigator	*Ref.*	*Locality*	α	β	γ
Fairbanks	11	Nevada	1.677_{Li}		
Larsen	29	California	1.670_{Na}	1.691_{Na}	1.692_{Na}
Lévy-Lacroix	31	Norway	1.650	1.712	1.728
Linck	30	Switzerland	1.678_{Na}	1.686_{Na}	1.689_{Na}
Peck	35	Nevada (pink)	1.677_{Na}	1.685_{Na}	1.690_{Na}
Peck	35	Nevada (lavender)	1.675_{Na}	1.685_{Na}	1.690_{Na}
Peck	35	Nevada (light blue)	1.675_{Na}	1.685_{Na}	1.692_{Na}
Walker	48	Canada	1.659_{Na}	1.684_{Na}	1.686_{Na}

Error = ± 0.003

Birefringence $(\gamma - \alpha) = 0.010$ to 0.027.

Dispersion. Strong but indeterminate. $\rho > v$ (25, 26, 32, 35) $\rho < v$ (1, 11, 27, 29, 44). Lacroix gives both $\rho > v$ (26, 32) and $\rho < v$ (27). In view of Schaller's (44) work $\rho < v$ seems to be correct.

Apparent optic axial angle (2E).

California (44) ---------$33°_{Li}$, $37°_{Na}$, $42°_{Cu}$.
Canada (48) -----------95°±.
Mexico (51, 52)---------50°±.
Uvildy Lake (25) -------Small.

True optic axial angle (2V).

Canada (48) -----------52°±.
France (44) ------------$35°_{Na}$ to $40°_{Na}$.
Madagascar (27) --------$35°40'_{Na}$.
Nevada (35) ------------30°–40°.
Norway (26, 32) --------$35° \pm_{Na}$.
Switzerland (30) --------Less than that of muscovite.

Pleochroism. Strong.

Locality	*Ref.*	α	β	γ
Bohemia	40	Deep blue Reddish brown Olive green Deep carmine Light olive green	Colorless	Colorless
Brazil	37	Light to dark blue Violet Dark wine red Bluish green Greenish yellow Dark green Greenish brown	Colorless	Colorless

Locality	*Ref.*	α	β	γ
California	44	Reddish purple	Colorless	Colorless
Canada	48	Berlin blue Some crystals show green interiors	Colorless	Colorless
France (Brignais)	44	Rose-salmon	Colorless	Colorless
Mexico	51, 52	Blue	Lilac red	Colorless
Moravia	39	Dark blue	Yellowish	Colorless
Nevada	11, 35	Blue, reddish, violet, lavender	Colorless	Colorless
Switzerland	30	Pistachio green	Colorless	Colorless
Other localities	1, 19, 26, 27, 32	Cobalt blue Light blue	Straw color Pale yellow Colorless	Colorless

Orientation. Z || a, X || c, Y || b.
Acute bisectrix is perpendicular to ~~c axis~~ (001)

Elongation. Parallel to c.

Inclusions. Diller (9, 10) observed liquid inclusions and long tubular cavities in dumortierite. Rutile and titanite inclusions are also common.

Pleochroic Haloes. Observed by Lacroix about inclusions of dumortierite in the cordierite of Norway.

D. Chemical Properties

Infusible before the blowpipe.

Loses color on strong ignition.

Yields a blue color when heated with cobalt nitrate on charcoal before the blowpipe.

Renders a salt of phosphorous bead slightly bluish and opaline.

Insoluble in acid including cold hydrofluoric acid. Quite resistant to weathering and hence found among detrital products.

Many specimens when fused with sodium carbonate will give a test for titanium with hydrogen peroxide.

When intimately mixed with potassium bisulphate and calcium fluoride and introduced into a colorless flame, the green flame of boron may be obtained, but this is a very delicate test and may fail.

The behavior of dumortierite on heating at high temperatures was investigated by Bowen and Wyckoff (3) who found that the mineral quickly turns white at 800° C and slightly turbid at 950°. The refractive index is slightly lowered and after 10 minutes heating at 1200° the average index becomes 1.61, the elongation becomes positive and the product shows characteristic X-ray spectrum lines of mullite [Vernadsky (47) had stated earlier that the decomposition product is sillimanite]. After two hours heating at 1400°, dumortierite completely breaks down to mullite ($3Al_2O_3.2SiO_2$) and probably silica and boric oxide. Boric oxide and water are completely expelled in 4.5 hours at 1500° at which temperature sintering begins. Liquid first appears at 1550° due to the melting of the eutectic between mullite and silica (1545°). For all practical purposes dumortierite at high temperatures behaves like a material containing only alumina and silica, nearly if not actually, in the proportion $4Al_2O_3.3SiO_2$, the formula which Damour originally assigned to the mineral.

ASSOCIATIONS OF DUMORTIERITE

Dumortierite commonly occurs as fibrous acicular, and fan-shaped inclusions in other minerals, chiefly in quartz, muscovite, feldspar, and cordierite. Occasionally, as in Humboldt Queen Canyon, Pershing County, Nevada, it occurs in large masses, but even here much of it is included in the quartz and muscovite.

The important minerals associated with dumortierite are indicated in the following table. Usually some other aluminum mineral is present, as andalusite, corundum, cyanite, pyrophyllite, sillimanite, or topaz. The common boron associate is tourmaline. While feldspar occurs with dumortierite in many localities, it is notably absent in some as in Madagascar, Mexico, Arizona, California, Nevada, New Mexico, and Washington. In some localities biotite and cordierite are present, chiefly as constituents of the country rock. Quartz, however, is an invariable associate, and muscovite is usually present either as a primary mineral or as an alteration product. In some places dumortierite has entirely altered to muscovite (sericite, or damourite). For example, spherulites in the Washington and New Mexico deposits have been observed by Schaller (44, 45) to be altered entirely into muscovite, and the same investigator has also observed pseudomorphs of muscovite after dumortierite in the French material (44). Sulphides are not commonly found accompanying dumortierite, but pyrite does occur in a few localities. Other minerals found with dumortierite are usually present in very small amounts as inclusions or as alteration products. (See table on pp. 16 and 17.)

Those minerals which have been found with dumortierite but which are not listed in the table are:

Brazil, Copacabana: beryl, graphite, monazite, pinite.
    Ipanema: monazite, pinite, spinel.

France, Rhône: chlorophyllite and fahlunite as alteration products of cordierite.

Germany, Wolfshau: chlorite.

Madagascar, Anfoka: lazulite.

Mexico, Guadalcázar: axinite, fluorite, hematite.

Norway, Tredestrand: spinel and wernerite as inclusions in cordierite; aspasiolite, esmarkite, polychroite, and praseolite as alteration products of cordierite.

Switzerland, Veltlin: chrysoberyl and chlorite as an alteration product of biotite.

United States—
    New York, New York City: xenotime and monazite as inclusions in quartz, monazite in orthoclase, torbernite (?), and autunite (?).
    Nevada, Granite Range: leucoxene.
        Humboldt Queen Canyon: chlorite, leucoxene.
    Washington, Skamania County: leucoxene.

MINERAL ASSOCIATES

Locality	Reference Number	Dike Rock	Country Rock
Argentina, Portrero, Catamarca	38		Granite
Bohemia, Pelrimov	24	Aplite	Granite gneiss
Brazil, Copacabana	37	Pegmatite	Cordierite gneiss
Ipanema	37	Pegmatite	Cordierite gneiss
Canada, Ashby Township	48, 53	Pegmatite	Gneiss
France, Department of Rhone	16, 17, 18	Pegmatite	Cordierite gneiss
Germany, Wolfshau	49	Pegmatite	
Madagascar, Anfoka	27		Quartzite (?)
Mexico, Guadalcázar	51, 52	Pegmatite	Granite
Moravia, Vymsylice	39	Pegmatite	Granite gneiss
Norway, Tvedestrand, etc.	26, 32		Cordierite gneiss
Russia, Uvildy Lake	25	Pegmatite	Basic igneous rock and gneiss.
Switzerland, Veltlin	30	Pegmatite	
Bergeller Massif	21	Pegmatite	Granite
UNITED STATES:			
Arizona, Clip, Yuma County	9, 10, 14, 15, 42, 43, 44	Quartz	1
Patagonia Mining District	a	Quartz	2
California, 6 mi. NW. Picacho Peak	a	Quartz	3
Imperial County	b		4
Riverside County	a	Quartz	5
San Diego County	14, 15, 42, 43, 44	Quartz	Biotite granite 6
Colorado, Canyon City	13	Pegmatite	Epidote schist 7
Nevada, Granite Range	a		Granite 8
Humboldt Queen Canyon	11, 35, a	Quartz	Sericite schist 9
Lincoln Hill	23	Quartz	Sericite schist 10
Round Mountain	a	Quartz	Granite 11
New Mexico, Luna County	45	Quartz	12
New York, New York City	4, 9, 10, 14, 15, 20, 42, 43, 44	Pegmatite	Mica schist Biotite gneiss 13
Washington, Skamania County	14, 15, 42, 43, 44	Quartz	14

a Work of Jones in this bulletin.

b Determination by Dr. Peck and communicated by Dr. Jeffery.

Ad Alteration product of dumortierite.

Id Inclusions in dumortierite.

OF DUMORTIERITE

Andalusite	Apatite	Biotite	Cordierite	Corundum	Cyanite	Garnet	Ilmenite	Magnetite	Muscovite	Orthoclase	Plagioclase	Pyrite	Pyrophyllite	Quartz	Rutile	Sillimanite	Titanite	Topaz	Tourmaline	Zircon	Other minerals	
X	----	----	----	X	----	----	----	----	X	----	----	----	----	X	----	----	----	----	X	----	----	
X	----	----	X	----	----	----	----	----	----	----	----	----	----	X	----	----	----	----	----	----	----	
Iq	X	X	----	----	----	X	X	----	X	X	X	X	----	X	X	----	----	X	Iq	Iq	X	
X	----	----	----	----	----	X	?	X	X	X	----	----	----	X	X	X	----	----	----	X	X	
------	----	----	----	----	X	----	----	----	X	X	----	----	----	X	----	----	----	----	X	----	----	
------	X	X	X	----	----	X	----	----	----	X	----	----	Ad	X	Id	----	----	----	Ib	----	X	
------	----	----	----	X	----	--	----	----	X	X	----	----	----	X	----	----	----	----	----	----	X	
------	----	----	----	----	----	----	----	----	----	----	----	----	----	X	----	----	----	----	----	----	X	
------	----	----	----	----	----	----	----	X	Ad	----	----	----	----	X	----	----	----	X	X	----	X	
------	----	----	----	----	----	----	----	----	----	X	----	----	----	X	----	X	----	----	----	----	----	
------	Ic	X	X	----	----	----	----	Ic	Ic	----	X	----	----	X	Ic	X	----	----	Ic	X	X	
------	----	----	X	----	----	X	----	----	----	----	----	----	----	X	----	----	----	----	X	----	----	
------	X	X	----	----	----	----	----	----	X	----	X	----	----	X	----	----	----	----	Im	----	X	
X	----	----	----	----	----	----	----	----	X	----	----	----	----	X	----	X	----	----	X	----	----	
------	X	----	----	----	X	----	----	X	X	----	----	----	----	X	X	----	----	----	----	----	----	
------	----	----	----	----	X	----	----	X	X	----	----	----	----	X	----	----	----	----	----	----	----	
------	----	----	----	----	----	----	----	X	X	----	----	----	----	X	----	----	?	----	----	----	X	
------	----	----	----	----	X	----	----	----	X	----	----	----	X	X	?a	----	----	----	----	----	----	
------	----	----	----	----	----	----	----	----	X	----	----	----	----	X	----	----	----	----	----	----	----	
------	X	----	----	X	----	----	----	----	X	----	----	X	----	X	?	X	?	Xa	----	X	X	
------	----	----	----	X	----	----	----	----	X	X	----	----	----	X	X	X	----	----	----	X	----	
------	----	----	----	----	----	----	----	----	X	----	----	----	----	X	X	----	X	X	----	----	X	
X	----	----	----	----	----	----	----	X	X	----	----	X	----	X	X	----	----	X	X	----	X	
X	----	----	----	----	----	----	----	----	X	----	----	----	----	X	----	----	----	----	----	X	----	
------	----	----	----	----	----	----	----	----	X	----	----	----	----	X	----	----	----	----	----	----	----	
------	----	----	----	----	----	----	----	----	X	----	----	----	----	X	----	----	----	----	----	----	----	
X	Iq	----	----	----	----	X	----	----	X	X	X	----	----	X	----	----	----	----	Iq	X	X	13
X	X	----	----	----	----	----	----	X	X	----	----	X	----	X	----	----	----	----	----	----	X	14

Ib Inclusions in biotite.
Ic Inclusions in cordierite.
Im Inclusions in muscovite.
Iq Inclusions in quartz.

CHEMICAL ANALYSES

Fifteen chemical analyses of dumortierite from ten different localities have been published by ten analysts. The following compilation of these analyses shows that no two of the ten analysts quite agree on the composition of the mineral. The causes of disagreement are: (1) small amount of material available for analysis, (2) difficulty of obtaining material of requisite purity, (3) difficulties inherent in methods of analysis, (4) failure on the part of some analysts to detect all constituents present, (5) the probability of vicarious replacement of aluminum by boron, hydrogen, iron and titanium.

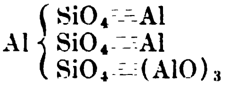
Dumortierite of all localities is so intimately associated with other minerals that material of sufficient purity for chemical analysis can be obtained only by employing special means of separation. Even then the material obtained may contain inclusions and therefore should be microscopically examined before it is analyzed. Often the amount of pure mineral obtainable is so small that considerable error is introduced in the analysis of the lesser constituent. Damour (6), in making the first analysis of dumortierite, introduced a method of purification which has since been used with modification by other analysts. Making use of the fact that dumortierite is not attacked by cold hydrofluoric acid while quartz and feldspar are, he treated his material with a mixture of hydrofluoric and sulfuric acids and obtained relatively pure dumortierite. This he further purified by drying, grinding and stirring in Thoulet's solution (potassium mercuric iodide). The dumortierite which sank in the solution was used for analysis. Ford (14, 15) reversed Damour's procedure. He crushed the mineral and first separated it from the lighter minerals by using Thoulet's solution and then barium mercuric iodide. Ford hand-picked the heavy concentrate and digested the selected material in cold hydrofluoric acid. Whitfield (9, 10) first used Klein's solution (cadmium borotungstate) and an electromagnet to get out the tourmaline but found the employment of Thoulet's solution and the digestion with hydroflouric acid to be a better procedure. Schaller (42, 43, 44) used only heavy liquid separation but made a careful microscopic examination of the material to be analyzed. Todd (48) used Braun's solution (methylene iodide) as the separating medium.

According to Schaller (44), "an anlysis of dumortierite is a difficult operation." He found (a) that the mineral must be fused with soda at least twice, (b) that the handling of large quantities of gelatinous aluminum hydroxide (plus those of iron and titanium) is cumbersome, (c) that a triple precipitation of the aluminum hydroxide is necessary, (d) that the Gooch method for the determination of boron is the best, providing all the known precautions are taken, (e) that the determination of water by ignition loss is not satisfactory.

Damour originally assigned the formula $4Al_2O_3.3SiO_2$ to dumortierite as a result of his analysis of Gonnard's material. He did not suspect the presence of boron. Subsequent spectroscopic analysis of a few hundredths of a gram of the French material indicated to Raoult (28) that the boron content of this material was much less than that obtained in American localities, but Ford (14, 15) had already pointed out that boron is not easily detected by qualitative tests. The difficulties involved in boron determinations are indicated by the wide range of results on dumortierite from a single locality, Harlem, New York. Whitfield reported only a trace of boron; Riggs found 4.07%, but his material was not entirely free of tourmaline, while Ford found 6.14%. Similar discrepancies in the determination of the water content are illustrated by Ford's and Schaller's analyses of the Clip dumortierite. In the fifteen analyses only six indicate the presence of titanium, a few show an entire absence of iron, while other analyses indicating high percentages of calcium, magnesium, sodium, and potash show that the material analyzed was not pure.

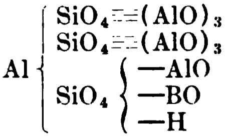
Although admitting that titanium and iron may replace aluminum, Schaller (44) held that "it has not been proved that either boric acid and alumina or boric acid and hydroxyl may mutually replace each other in minerals as flourine and hydroxyl are known to do. There is, then, no reason that the writer can see why the alumina, boric acid, and water in dumortierite should not be present in fixed quantities and that the variations shown in analyses are not due to isomorphous replacements, but to inaccuracy of analyses or impure material." Ford and others do not agree with this, but at the present time the formula for dumortierite which are considered best are Schaller's (44), $8Al_2O_3.B_2O_3.6SiO_2.H_2O$, and Todd's(48), $8Al_2O_3.B_2O_3.7SiO_2.H_2O$. These differ by only one molecule of SiO_2. Structurally Schaller has made his formula for dumortierite similar to that of andalusite:

Andalusite



$$Al\left\{\begin{array}{l} SiO_4\equiv Al \\ SiO_4\equiv Al \\ SiO_4\equiv (AlO)_3 \end{array}\right.$$

Dumortierite



$$Al\left\{\begin{array}{l} SiO_4\equiv (AlO)_3 \\ SiO_4\equiv (AlO)_3 \\ SiO_4\left\{\begin{array}{l} -AlO \\ -BO \\ -H \end{array}\right. \end{array}\right.$$

Argentina. Portre
Canada. Ontario --
France. Beaunan-
Madagascar. Anfe
Switzerland. Veltl
UNITED STATES:
Arizona. Clip-

California. San

Nevada ....
New York, Ha

Washington,

	Na_2O
4	0.9
7	------
5	------
8	0.1
3	------

7	------
2	0.

4	2

7	1

)	Na_2O	K_2O	P_2O_5	MnO	Ig. Loss	Total	Proposed formula
4	0.96	3.62	--------	--------	3.02	99.55	Impure
7	--------	--------	--------	0.11	1.32	99.99	$8Al_2O_3.B_2O_3.7SiO_2.H_2O$
5	--------	--------	--------	--------	2.25	99.58	$4Al_2O_3.3SiO_2$
8	0.18	0.05	--------	--------	1.29	100.23	$(Al,B)_8Si_3O_{18}$
8	--------	--------	--------	--------	1.31	98.43	Impure
--	--------	--------	--------	--------	1.41	100.32	$(AlO)_{16}(Al,B,H)_4(SiO_4)_7$
r	--------	--------	0.20	--------	1.72	99.34	$3Al_8Si_3O_{18}.AlB_3O_9.2H_2O$
2	0.37	0.11	--------	--------	1.34	100.14	Impure
--	--------	--------	--------	--------	2.14	100.84	$(AlO)_{16}(Al,B,H)_4(SiO_4)_7$
--	--------	--------	--------	--------	1.52	100.56	$8Al_2O_3.B_2O_3.H_2O.6SiO_2$
s	2.66	--------	--------	--------	Loss free basis		
--	--------	--------	--------	--------	2.09	100.83	Impure material
7	1.72	1.04	--------	--------	2.96	100.52	$(Na,K)_2O.10Al_2O_3.B_2O_3.10(SiO_2).3HO_2$
--	--------	--------	--------	--------	--------	100.35	
--	--------	--------	--------	--------	2.12	100.03	Impure

THE GEOLOGY OF THE DEPOSIT OF DUMORTIERITE IN HUMBOLDT QUEEN CANYON, PERSHING COUNTY, NEVADA

GENERAL GEOLOGY

By J C. Jones
Professor of Geology and Mineralogy, Mackay School of Mines

While dumortierite is a rare mineral, yet it has been found practically the world over associated with granites, pegmatite dikes, high temperature quartz veins, and contact metamorphic deposits. With the recent discovery that an addition of dumortierite makes an unusually tough and valuable porcelain the search for suitable deposits has been stimulated. It is essential, aside from a sufficient quantity and accessibility, that a deposit be practically free from quartz and other associated minerals, though such minerals as andalusite and muscovite can be tolerated in considerable amounts.

At present only one suitable deposit has been found, the deposit on the west slope of the Humboldt Range near Oreana, Nevada, owned and operated by the Champion Porcelain Company, of Detroit, Michigan. The chief geological problems suggested in a study of this deposit are the determination of the mode of occurrence and origin that determines the suitability of the dumortierite of this locality in contrast to the unsuitability of other known occurrences of the desired mineral.

Summarizing the results of the present study, it may be stated that the dumortierite used from this locality is won from lenticular masses occurring in zones formed by solutions originating in a granitic magma that intruded the region. While dumortierite also occurs in quartz veins as in other known localities, yet the lenticular masses originated through the replacement of pre-existing lenses of andalusite formed during an earlier stage in the metamorphism of the rocks by the granitic magma. During the period of replacement of the andalusite little quartz was deposited, the quartz-dumortierite veins forming later. Thus the lenses contain only the tolerated minerals and can be utilized, while the veins are worthless.

The deposit operated by the Champion Porcelain Company is located six miles due east of Oreana, Nevada, a station on the transcontinental line of the Southern Pacific railroad. The area is just beyond the northwest corner of the geologic map (23, plate 1)[1] of the Rochester District and about three and a half miles northwest of Lower Rochester. The deposit lies near the head of a small canyon locally known as Humboldt Queen Canyon located between Limerick Canyon to the south and Sacramento Canyon to the north. On the map of the Fortieth Parallel Survey[2] Limerick Canyon is designated as Sacramento Canyon, but at present the large canyon two miles north is known as Sacramento Canyon.

The geology of the Humboldt Range has been well summarized by Knopf (23) in a description of the geology of the Rochester District.

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[1] The numbers refer to the articles listed in the Bibliography.

[2] King, Clarence. Geol. Surv. 40th Par. Atlas. Map V, east half.

The Humboldt Range is largely composed of a thick series of lavas, volcanic tuffs and breccias in part interbedded with sediments chiefly limestones, shales, and sandstones of middle and upper Triassic age. As the igneous rocks largely lie below the sediments the Fortieth Parallel Survey[1] separated the Triassic rocks into two groups, naming the lavas the Koipato, the sediments the Star Peak Formation. During the close of the Mesozoic Era these were intruded by granites and folded. In the Rochester District the structure is a broad anticline that pitches to the south. The rocks forming the western limb of the anticline have a general strike of N. 30 deg. W. and dip 30 deg. westerly. Accompanying the intrustion of the granitic rocks were heated solutions that introduced the ore and mineral deposits found in the Rochester District.

During the following geologic periods erosion was active denuding the mountain range and depositing the débris in the valleys. Towards the close of the Tertiary Era extensive faulting began to reelevate the mountains and continued to the present, as is evidenced by recent fault scarps at the base of the range and the steep walled canyons that notch the range. This latest movement has been accompanied at times by the outpouring of basaltic lavas.

The greater part of the rocks exposed in the Rochester District are Triassic lavas belonging to the Koipato group. Knopf (23. p. 23) estimates their thickness as between 10,000 and 15,000 feet. In Limerick Canyon the rocks are chiefly trachytes and keratophyres intruded by irregular areas of aplite and dikes of granite prophyry.

The trachyte, as described by Knopf, comprises a series of lavas, tuffs, and volcanic breccias; light colored, felsitic, and usually containing inconspicuous phenocrysts of microcline only, although a few quartz phenocrysts occur in the upper layers of the series. While the lavas are usually massive, the tuffs and breccias are more or less schistose.

Near the head of Limerick Canyon an area of the trachyte was but little altered and Knopf found in a study of the darker colored rock that it had numerous slender phenocrysts of microcline in a sperulitic ground mass, the spherulites dusted with minute specks of iron oxide. In addition, minor amounts of apatite, titanite, and zircon were found. A small amount of secondary quartz occurred as veinlets and partial replacement of some of the microclines. A fresh specimen of this rock was analyzed by R. C. Wells (23, p. 16) with the following results:

SiO_2	67.01%
Al_2O_3	15.97%
Fe_2O_3	2.54%
FeO	.44%
MgO	Trace
CaO	.19%
Na_2O	1.92%
K_2O	11.42%
H_2O	.28%
TiO_2	.39%
Total	100.16%

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[1] U. S. Geol. Explor. 40th Par. Rept. vol. 1, p. 269, 1878.

The extremely high percentage of potash and relatively low percentage of silica indicates that the rock is a trachyte.

On the west slope of Lincoln Hill a considerable area of the trachyte has been profoundly altered and replaced by quartz, sericite, andalusite, and dumortierite. The underlying breccias strike N. 20 deg. W. and dip 25 deg. westerly. The dumortierite occurs as lavender to pink splotches in the schist and as a network of quartz-dumortierite veins. The original texture of the trachyte has been completely obliterated and the rock consists of the four minerals mentioned. Knopf (23, p. 19) believes the alteration of the trachyte is due to the action of gases containing boron that escaped from the underlying granitic magma as it cooled and solidified.

The keratophyres are dark colored tuffs, breccias, and lavas, with phenocrysts of albite, chlorite pseudomorphs after pyroxene, and some quartz. Due to metamorphism the keratophyres are largely schistose with an abundance of black tourmaline and biotite. The contact of the keratophyres and trachytes is somewhat uncertain as they are interbedded through a transition zone of from 500 feet to one thousand feet in thickness.

Three types of intrusive rocks were recognized, a meta-diorite of Triassic age, aplites and granite-porphyries of post-Triassic age. The porphyries are believed to be responsible for the solutions that deposited the dumortierite and metalliferous veins.

The deposits of dumortierite in Humboldt Queen Canyon occur near the head of the canyon at an elevation of approximately 5,500 feet above sea level and about 1,000 feet above Oreana. The road from Oreana leads across the flat floored Humboldt Valley to the foot of the mountains, then rises rapidly due east through the steep-walled canyon. At the property of the Champion Porcelain Company, the canyon branches, the main canyon turning south, with a branch to the north and a minor saddle continuing east.

The dumortierite occurs in two parallel zones striking east of north and dipping west. The western zone, located at the fork of the canyon, is marked by a bold outcrop of massive quartz several hundred feet long, fifty feet wide, striking N. 20 deg. E., and dipping 55 deg. westerly. Little development work has been done upon it as yet. The eastern zone is about 600 feet east from the western zone and continues up the northern branch of the canyon. This zone is 75 feet wide, strikes N. 15 deg. E., dips 50 deg. W., and has furnished the bulk of the dumortierite obtained up to the present time. North and south of the saddle, the zone is marked by bold outcrops of massive quartz through which are numerous stringers and veins of quartz and dumortierite. At the saddle, however, the zone is inconspicuous and large boulders of nearly pure, massive dumortierite were found along and below the zone. The greater part of the production has come from these boulders and lenses found in and near the saddle. It is evident that the saddle has formed due to the somewhat softer character of the rocks in this portion of the zone.

The deposits have been explored by numerous open cuts and shallow tunnels in the zone as it crosses the saddle and by about 1,000 feet of work in the lower tunnel driven to intersect the zone at depth. The surface workings follow the zone up the gulch to the north and it is apparent that the masses of high grade dumortierite are most abundant in an elongate area or shoot pitching about 35 deg. to the south. This shoot lies on the southern end or toe of the large outcrop of massive quartz to the north.

The lower tunnel cut the dumortierite zone about 160 feet from the portal and at 180 feet intersected a diabase dike that at the time seemed to be the footwall of the zone. The tunnel then was turned to the north and followed the dike for 300 feet. At this point it became apparent that the dike had crossed the zone at a low angle and a crosscut was driven east through the zone behind the dike. This crosscut is under the southern end of the massive quartz outcropping up the northern branch of the canyon. For the first few feet the crosscut is in altered schist that soon changes to massive quartz which continues for 75 feet to the schist that forms the footwall of the zone. While the massive quartz contains numerous stringers and small lenses of dumortierite, muscovite, and quartz, yet none of the large masses of pure dumortierite were encountered.

A second crosscut was then driven where the tunnel first encountered the dike and on breaking through, a large lense of dumortierite was found. This lense was spindle shaped and about 38 feet long, 15 feet high, and 7 feet wide, tapering at both ends. The longer axis pitched 35 deg. to the north lying across the general pitch of the shoot as disclosed in the surface openings. The lense lay on massive quartz with schist hanging walls and stringers of dumortierite leading from the lense. This seems to be the common mode of occurrence of the lenses found in place near the surface in the saddle.

The course of the diabase dike varies from N. 10 deg. W. in the southernmost exposure in the tunnel, then turns on an arc parallel to the zone for 125 feet, then again turns N. 10 deg. W. cutting across the zone. At the northern end of the tunnel the dike again turns a few degrees east of north and follows parallel to the zone. It is probable that the dike follows more or less closely the hanging wall of the massive quartz but not so closely but that occasional pockets of the softer altered schist and dumorterite lenses are included between the dike and the quartz as in the area where the recent mass of dumortierite was found. Unfortunately the surface is deeply covered with debris and the dike does not outcrop. The westerly dip of the dike varies from 45 deg. to 70 deg., and the width from 20 to 35 feet. As the dike has numerous apophyses cutting arcoss the schistosity and the dumorterite veins and lenses it is evident that the dike was injected after the dumorterite had formed and that its approximate parallelism to the zone is due to the relative weakness of the zone offering a readier avenue of flow than the surrounding rocks.

MEGASCOPIC MINERALOGY

By O. R. Grawe

The dumortierite in Humboldt Queen Canyon shows a diversity of characteristics because of its various modes of occurrence. These may be classified as three main types:

(1) Nearly pure dumortierite of shipping grade, occurring in lenses within sericite schist and as residual surface boulders in the alluvium above the schist.

(2) Dumortierite in veins and stringers cutting quartz or as fibrous inclusions in the quartz.

(3) Dumortierite in veins and stringers in sericite schist or as fibrous inclusions in the sericite.

For practical purposes it may be feasible to further subdivide classes 2 and 3 in accordance with the specific manner of occurrence of the dumortierite, its associations and abundance.

No regular arrangement of dumortierite is apparent in the quartz. It fills fractures in the quartz and quartz fills fractures in the dumortierite. Much of the dumortierite is included in the quartz as fine, inseparable hair-like fibers which give their color to the gangue material. Andalusite is associated with dumortierite and quartz in such an intimate way that very often the andalusite can only be distinguished from the quartz with the aid of a microscope. Mica is a minor associate in this mode of occurrence except where this mode of occurrence grades into the third type.

Mica and dumortierite occur together in a variety of ways. Granular intergrowths of the two range from a microscopic texture to that containing grains of granular aggregates up to a half centimeter in diameter. In many instances dumortierite veins cut the sericite, in others dumortierite apparently has replaced the sericite along the planes of schistosity, producing an interlamination of dumortierite and sericite. Where subsequent movement has taken place the two have been crenulated and compressed together so that the rock takes on a talc-like appearance. Dumortierite also is found intimately mixed with a matrix of sericite, quartz, and andalusite and as fibrous inclusions in the mica, coloring the mica as it does the quartz. Pyrite is a rare associate but is found with dumortierite in the schist.

From the pure mineralogical standpoint it was considered best to select four type specimens of the purest dumortierite and describe them. In general this dumortierite is like previously described material showing a wide range of colors from intense blue to deep pinkish lilac. The luster of the massive material is mat or dull and the streak is nearly white. The hardness is between 6 and 7 and the massive material is very tough due, no doubt, to the close intergrowth of many fibers. An aggregate of transparent prismatic cystals without terminal faces was observed in the schist but, because of their incompleteness, these crystals were not studied in detail. They are dull violet blue and match best the Ridgway color 53 V–B. Other properties of dumortierite from the vicinity of Humboldt Queen Canyon have been described by Fairbanks (11) and by Peck (35).

In the following table certain variable properties of the selected dumortierite specimens are tabulated together with analyses of the material as determined by C. W. Davis of the Rare and Precious Metals Experiment Station of the U. S. Bureau of Mines.

The colors of the hand specimens were determined by comparing the samples with the Ridgway color chart. No tint photometer readings could be made because of lack of suitable material in pieces large enough for the purpose. The streaks were determined both by comparison with the Ridgway chart and by analysis by means of the Ives Tint Photometer according to the method described by the distributors of the instrument and according to the suggestions made by the present writer (Science, n. s., Vol. LXVI, pp. 61, 62, 1927). Material for the determination of the streak was prepared by grinding selected fragments of the mineral in an agate mortar to pass a 1/16 mm. screen. This fine powder was poured on a piece of cardboard approximately 4 square inches in area and rolled smooth under a four kilogram weight, a second piece of cardboard being inserted between the weight and the material during the rolling. This insured a uniform compactness to all specimens analyzed. The cardboard covered by the compressed powder was then placed on the magnesia block of the photometer and color readings were taken in the usual way. The readings tabulated are the mean of five. Specific gravity determinations recorded in the table represent the average Jolly balance determinations of five samples of each specimen.

Davis analyzed three specimens of the dumortierite described above. The material was ground to pass a 200 mesh screen and, in accordance with instructions, no attempt was made to purify it. The general method of analysis was that for silicate rocks outlined by W. F. Hillebrand (U. S. Geol. Survey Bull. 700, 1919) but modified to take into account the precautions of Schaller (44). Titanium was determined colorimetrically, boron according to the Gouch-Low method as modified by Chapin (J. Am. Che. Soc. Vol. 30, pp. 1691–1701, 1908), and the alkalies were determined by the J. Lawrence Smith method.

From the chemical analyses the theoretical mineral compositions of the analyzed materials were calculated. These computations are based on the minerals observed by Jones in his study of the thin sections of the material analyzed. The following assumptions were made:

(1) That all the K_2O is contained in muscovite ($Al_3KH_2Si_3O_{12}$), av. sp. gr. 2.85.

(2) That all the Na_2O is contained in paragonite ($Al_3NaH_2Si_3O_{12}$), av. sp. gr. 2.90.

(3) That all the B_2O_3,Ti_2O_3 and Fe_2O_3 is contained in dumortierite, av. sp. gr. 3.30.

(4) That all Al_2O_3 in excess of that needed to form micas and dumortierite produced andalusite (Al_2SiO_5), av. sp. gr. 3.18.

(5) That all excess SiO_2 formed quartz (SiO_2), av. sp. gr. 2.65.

No account was taken of the MgO which may form some colorless phlogopite. The calculated specific gravities are the sums of average specific gravities of the theoretical minerals weighted according to their abundance.

The first set of mineral analyses is based on Schaller's formula for dumortierite, $8Al_2O_3.B_2O_3.H_2O.6SiO_2$, in which titanium and iron may replace aluminum. The results based on this formula are at fault because the calculated percentage of andalusite for specimen 1 is far greater than that actually observed in the thin section, which shows only 1–2% of andalusite. The per cent of dumortierite is too low. The most serious objection, however, is apparent in the analyses of specimens 2 and 3. Here there is a notable excess of boron, an excess sufficient to make itself apparent in the thin sections in some mineral other than dumortierite, but such a mineral was not observed by Jones. Calculations based on Todd's formula, $8Al_2O_3.B_2O_3.H_2O.7SiO_2$, lead to similar results. For specimen 1 the following mineral composition was determined:

Muscovite	6.45%
Paragonite	2.72%
Dumortierite	59.96%
Andalusite	12.51%
Quartz	13.01%
Total	94.65%

Sp. gr. 2.99

Since these computations did not agree very well with the microscopic study, other computations were made based on Ford's formula, $(AlO)_{16}(Al,B,H)_4(SiO_4)_7$, which makes allowance for the possible replacement of aluminum by boron and hydrogen, and of course the replacement of aluminum by titanium and iron is not ruled out. This formula has the advantage that all the boron can be calculated as being in dumortierite. Further, much more of the water can be calculated as combined in the known minerals. The per cent of dumortierite is increased in specimen 1 and not notably changed in the other two. While the calculation shows the absence of andalusite whereas the mineral is actually known to be present, the error made is smaller in this case than in those based on the formula of Todd and of Schaller. Moreover, if Schaller is correct in saying that the determination of water by the ignition loss method yields high results, then it is possible by reducing the water content to have Al_2O_3 in excess of that required by the Ford formula and such Al_2O_3 could be calculated as andalusite. The calculated specific gravities are not notably different, those based on Ford's formula being slightly better. The total mineral compositions as calculated on the basis of Ford's formula for dumortierite are also better than those based on the formulas of Todd and of Schaller.

In summary, then, it may be stated that the mineral composition of the specimens of dumortierite as computed from chemical analyses agree best with observed facts when the percentage mineral composition is based on Ford's formula for dumortierite.

ANALYSES OF DUMORTIERITE FROM GYPSY QUEEN CANYON, NEVADA

Number of sample		1	2	3	4
Color of hand specimen (Ridgway)		Tourmaline pink 67′ V-R b	Light vinaceous purple 65‴ RR-V b	Dark lavender 61‴ VR-V b	Grayish violet-blue 58* V-B i
Color of streak (Ridgway)		Pale rhodonite pink 71′ V-RR f	Pale vinaceous lilac 69‴ RV-R f	Vinaceous lavender 65‴ RR-V f	Grayish lavender 57‴ VB-V f
Streak color as determined by the Ives Tint Photometer	Red	82.5	72.0	67.0	62.0
	Yellow	77.0	67.0	65.5	60.0
	Green	71.5	62.0	63.0	60.5
	Blue violet	67.0	60.0	62.5	62.5
	Peacock blue	67.0	60.0	62.0	62.0
Percent admixture of black as calculated from photometer readings		26.86	36.30	36.29	39.01
Specific gravity (Jolly Balance)		2.99	3.26	3.23	3.13
Chemical analysis[a] Results in per cent	SiO_2	40.83	37.10	33.24	Not analyzed
	Al_2O_3	47.67	53.63	57.42	
	Fe_2O_3	0.14	0.16	0.18	
	Ti_2O_3	0.65	0.72	0.75	
	B_2O_3	3.15	4.80	5.40	
	CaO	None	None	None	
	MgO	0.13	0.15	0.11	
	Na_2O	0.22	0.22	0.24	
	K_2O	0.76	0.35	0.34	
	H_2O (<110° C)	0.38	0.17	0.11	
	H_2O (>110° C)	6.18	2.65	2.31	
	Total	100.11	99.95	100.10	
Mineral analysis calculated from chemical analysis using Schaller's formula for dumortierite Results in per cent	Muscovite	6.45	2.97	2.88	
	Paragonite	2.72	2.72	2.97	
	Dumortierite	57.26	80.92	86.72	
	Andalusite	12.53	None	None	
	Quartz	15.71	11.41	5.87	
	Total	94.67	98.02	98.44	
	Excess B_2O_3	None	0.25	0.62	
	Excess MgO	0.13	0.15	0.11	
	Excess H_2O (>110° C)	5.07	1.25	0.82	
Calculated sp. gr.		2.97	3.14	3.18	
Mineral analysis calculated from chemical analysis using Ford's formula for dumortierite Results in per cent	Muscovite	6.45	2.97	2.88	
	Paragonite	2.72	2.72	2.97	
	Dumortierite	68.74	80.42	86.26	
	Quartz	18.12	11.89	7.41	
	Total	96.03	98.00	99.52	
	Excess MgO	0.13	0.15	0.11	
	Excess H_2O (>110° C)	3.51	0.65	0.36	
Calculated sp. gr.		3.01	3.13	3.21	

PETROGRAPHY

By J C. Jones

A number of thin sections of the dumorterite and associated rocks were made and studied under the microscope. In the material analyzed by Davis and studied megascopically by Grawe the dumortierite occurs as a felt of minute, elongate crystals, one-quarter to one-half millimeters in length and one to fifteen microns in width. These are embedded in plates of muscovite up to a millimeter in diameter. A few minute crystals of rutile and titaniferous magnetite occur sparsely distributed through the felt. A small amount of iron stain occurs in splotches in the vicinity of the titaniferous minerals together with a little leucoxene. Occasional clear spaces are present, filled with fine grained quartz and sericite. The dumortierite crystals projecting from the felted ground mass into the clear spaces have rounded terminations that occasionally resemble low angled domes. Aside from the variation in the relative proportions of the minerals the only essential difference in the three specimens is that in the blue material the clear spaces contain crystals of topaz intergrown with quartz which are absent from the other specimens.

The second grade material offered a greater variety of minerals and gave a clew to the mode of origin of the deposits. Quartz occurs for the most part as areas of irregular outline or in mosaics of intimately intergrown crystals with irregular boundaries, a "jasperoid" structure typical of quartz that has replaced pre-existent minerals and rocks. In the veinlets, on the other hand, the quartz crystals are euhedral although there is no relationship between the orientation of the crystals and the walls or comb structure.

The dumortierite had four microscopic phases or modes of occurrence:

(1) As a felt of sheaves or rosettes of minute crystals as in the high grade material.

(2) As capillary crystals in and through the quartz, muscovite, and sericite. Sometimes these fine crystals of dumortierite were bunched as sheaves and rosettes or in brushes when they progressed from the matrix out into the veinlets of quartz, but for the most part they were irregularly arranged as spots and individual crystals in the groundmass. One instance was noted where three lines of crystals were oriented parallel to the walls in a small quartz vein dividing it into four equal parts.

(3) Rarely as large crystals usually blue and violet in color in contrast to the usual lavender and pink shades of the finer crystals. Occasionally the large crystals had both blue and pink colors irregularly distributed in the same crystal.

(4) As powdery masses of submicroscopic particles dusting the quartz and muscovite crystals.

Muscovite occurred in large foils and plates frequently colored pink by capillary crystals of included dumortierite. Damourite occurred sometimes as fairly large flakes but for the most part as minute foils of sericite. There is the usual uncertainty that some of the sericite may be pyrophyllite but none of the latter mineral occurred in large enough crystals to be recognized in the hand specimens.

Andalusite was observed as large grains up to several millimeters in diameter and in all stages of replacement by the minerals mentioned previously. The replacement proceeded along the cleavage cracks or started in isolated areas within the crystals and progressed by stages. The preliminary stage was generally a granulation of the andalusite in which the borders of the crystals broke into a dusty aggregate of grains that extinguished in harmony with the unaltered crystal indicating that there had been no movement of the individual grains during the period of granulation. Then needles of dumortierite accompanied by sericite penetrate the granular mass eventually changing it to a mixture of dumortierite and muscovite as observed in the high grade material. Later quartz, sericite, and dumortierite were deposited in irregular patches and in veinlets replacing to some extent the earlier formed minerals. Finally quartz veins with a minor amount of dumortierite and sericite cut through the replaced mass as the last deposit from the solutions causing the alteration of the andalusite.

Minute grains of andalusite the same size as the granules in the granulated andalusite occur in the quartz and in a number of instances they were clearly dragged from the original borders of the large crystals by the solution as it deposited the quartz veinlets.

Small grains of rutile and titaniferous magnetite, with the accompanying oxidation products leucoxene and iron oxides, were scattered sporadically through the rock. A few instances were noted where pyrite had been deposited in altering andalusite along with the sericite, quartz and dumortierite.

A slide of the rock forming the hanging wall of the east dumortierite zone disclosed residual phenocrysts of microcline and rare quartz, a few grains of titanite, needles of tourmaline, and angular fragments of tuffaceous inclusions with spherulitic texture in a schistose groundmass of granular quartz and sericite. The rock corresponds closely to the trachyte as described by Knopf.

The footwall rock is somewhat darker in color and is essentially a quartz-sericite schist containing veins of quartz and black tourmaline. The microscope disclosed crystals of titaniferous magnetite and titanite with leucoxene, biotite foils and patches of chlorite, and outlines of feldspar crystals and tuff fragments replaced by a fine-grained aggregate of secondary quartz and sericite. No residual quartz phenocrysts were noted. The rock is similar to the keratophyres.

The rock in the face of the crosscut under the massive quartz is an altered quartz-sericite schist with a few quartz phenocrysts as the only representatives of the minerals in the original lava. Along the hanging wall of the diabase dike occasional thin streaks of dark colored schist occur which have quartz residuals and outlines of feldspars now completely replaced with a fine grained aggregate of quartz and sericite. Euhedral crystals of black tourmaline are abundant that cut across the planes of the schistosity and have evidently been formed after the development of the schist.

As nearly as can be judged the zone has formed in the transition zone between the trachytes and the keratophyres where the two types of lavas are interbedded. While no definite statement can be made at present as to the attitude of the different beds, it is probable that the zone dips somewhat more steeply than the beds and cuts them at a low angle.

ORIGIN OF THE DEPOSIT

By J C. Jones

Frequently in a study of rocks metamorphosed through contact with an invading magma several stages can be identified and a sequence in the process of alteration be recognized. The data at hand indicates the following history of the deposits in Humboldt Queen Canyon:

(1) The interbedded series of trachytes and keratophyres forming the transition zone between the two types of lavas were altered to quartz-sericite schists by the increased temperature and differential pressure incident to the intrusion of the granitic magma.

(2) Zones of weakness developed cutting the beds at a low angle and offering channels for the transmission of fluids escaping from the cooling and solidifying magma below.

(3) These fluids at first were probably liquid and changed the schists in the channels to massive, elongate bodies of quartz with subordinate lenses of andalusite.

(4) Solutions, probably gaseous, next introduced potash, boron, and water that replaced the andalusite forming the high grade dumortierite as mined and the isolated crystals of black tourmaline found in the keratophyres.

(5) The final solutions, probably liquid, introduced the quartz, dumortierite, sericite veins found in the zones and quartz, black tourmaline veins found elsewhere. These final solutions eventually deposited the metalliferous veins found in the vicinity.

This history as sketched does not imply any sharp demarcation of the stages but rather the changing conditions under which the solutions reacted during the slow cooling of the magma. Our knowledge of the physical-chemical laws governing the processes of solidifying magmas with the attendant alteration of the invaded rocks is so scanty that conjecture only is possible.

A very suggestive study of the reactions of water, potash, and silica at temperatures between 200° C. and 1000° C., was accomplished by Morey.[1] In discussing his results he states that the solubility of silica in water is very slight and not enough to appreciably affect the critical point of water. If silica is melted in an atmosphere of water vapor a certain amount of the water will dissolve, depending on the pressure, and lower the freezing point of the silica. As the pressure is increased more water will enter into the solution and the freezing point of the silica be depressed until a second critical point probably at 550° C., and zero concentration of silica is reached. At this point both phases are practically pure water. The addition of potash causes immediate disappearance of the critical field and the pressures must be enormous. He also found that at temperatures above 500° C. potash was volatile but that no evidence of silica could be found in the vapor phase.

As the evidence obtained with the microscope indicated that the andalusite was replaced with a mixture of dumortierite and muscovite the following equation is suggestive:

$$\underset{\text{(andalusite)}}{15Al_2SiO_5} + \underset{\left(\substack{\text{potassium}\\ \text{metaborate}}\right)}{2KBO_2} + \underset{\left(\substack{\text{metaboric}\\ \text{acid}}\right)}{HBO_2} + \underset{\text{(water)}}{3H_2O} =$$

$$\underset{\text{(muscovite)}}{2Al_3KH_2(SiO_4)_3} + \underset{\text{(dumortierite)}}{3Al(AlO)_7(BO)H(SiO_4)_3}$$

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[1] Morey, Geo. W., Jour. Am. Chem. Soc. Vol. 39, pp. 1173–1229, 1917.

As the components introduced into the andalusite are known to be volatile at temperatures above 500° C., and to be present in the emanations given off by solidifying magmas it is probable that these solutions were gaseous at the time of the formation of the high grade dumortierite. The latter introduction of the quartz veins would be delayed until the solutions had cooled below the critical temperature of water (365° C.) as is indicated by a slight replacement of the dumortierite and muscovite. It is possible that most of the andalusite grains found in the quartz veins are residuals though some may have been deposited with the quartz.

The dumortierite then was formed in two distinct stages; one as a replacement of pre-existent andalusite, probably by gaseous solutions at temperatures above 500° C.; the other by liquid solutions below the critical temperature of water in the vicinity of 365° C., as a component of the quartz veins. An examination of specimens from about a dozen other localities indicated that in every instance the dumortierite was deposited with quartz, and the first mode of deposition was absent.

As an excess of silica is undesirable in the manufacture of the porcelain sought and as the deposit near Rochester is the only occurrence known at present that furnishes suitable material, the inference is clear that only such deposits as have formed through the replacement of andalusite are of present commercial value.

Prospecting for deposits of dumortierite should be confined to the areas in the vicinity of granites and other acid magmas in contact with aluminous rocks. Such rocks are present in the Triassic lavas of Northern Nevada and have been intruded in a number of localities by granites. As the lavender color of the dumortierite is distinctive it will probably be first noted in quartz veins associated with light colored mica schists. If in addition bodies of andalusite occur in the vicinity it is probable that a suitable deposit of dumortierite will be found indicated by large boulders and masses of the purer material on the surface.

THE MINING OF DUMORTIERITE

By JAY A. CARPENTER
Professor of Mining, Mackay School of Mines

At the present time the mining of dumortierite in the United States is confined to one mine and that is the mine of the Champion Porcelain Company, about six miles east of Oreana, Nevada. Oreana is the station on the Southern Pacific serving the Rochester Mining District, and is 14 miles north of Lovelock, Nevada.

At the present time the actual mining of dumortierite at this mine is limited to simple opencut work on a hillside. The dumortierite being mined is in the form of small and large boulders occurring either in the overburden of a few feet in thickness above the schist or projecting out of the enclosing schist formation. For a detailed description of the deposit the reader is referred to the section of this bulletin devoted to the geology of the deposit. For the purpose of describing the mining of the material it is sufficient to say that the dumortierite of present commercial value occurs as segregated lenticular masses in a schistose rock that is probably of a metamorphosed igneous origin. The boulders outcrop on the western slope of a hill over a width of about 100 feet and a length of 600 feet, the length conforming with the planes of schistosity in having a general north-south course. The dip of the schistosity is about 45 degrees to the west which may also indicate the dip of the ore zone. The dumortierite occurs in this schist much as plums do in a plum pudding. It is interesting to note also that the dumortierite has a minor schistosity conforming with that of the schist.

The first mining of dumortierite for shipment consisted merely of bulldozing outcropping boulders along lines of weakness or in short hand-drill holes, using 60% dynamite. The rock was broken just small enough to load on pack horses to take it down the steep gulch to where the freighting wagons of R. H. Rowland could then transport it to Oreana for rail shipment to Detroit.

This particular outcrop of violet or purplish colored boulders was included by chance in a location made in 1917 by R. H. (Slim) Rowland on account of narrow silver-bearing quartz veins occurring in the schist just over the brow of the hill from the outcropping boulders. It was not the large boulders that interested Mr. Rowland but rather the narrow veinlets of a blue mineral that brought to mind the usual prospector's hope that his blue mineral might be the elusive silver bromide. Later Mr. Rowland "found out that the mineral was dumortierite through a party gathering specimens and after that found out that it was of no commercial value." Years later stirred to action by the publicity given to the mining of "spark plug mineral" near Bishop, California, by the Champion Porcelain Company, Mr. Rowland sent samples of the dumortierite to that company early in 1925. Dr. Joseph A. Jeffery, the president of the company, visited the property in April, and with a growing appreciation of the size of the deposit and the value of the mineral as a refractory, the property was purchased in October of that year. The first carload shipments were made from "grass roots" or more strictly speaking from the boulders sticking above the sparse sagebrush.

Due to the high hardness and toughness of these boulders, small fragments of this pretty colored and attractive looking mineral now salt the hillsides for a quarter of a mile around the main outcrop as a result of the blasting of the boulders. A tenderfoot, even today, might wonder how such a promiscuously mineralized area could have lain undiscovered for so long a time.

By October, 1926, the wagon road had been extended as far as practical up the gulch and at this point a neat compressor plant was installed. The compressor is an Ingersoll-Rand portable gasoline engine driven unit of the 10″ x 8″ type "Twenty," capable of running two or three jackhammers and the No. 33 Leyner sharpener. The oil forge for the sharpener is lined with a refractory brick of exceptional qualities made for experimental purposes by the Champion Porcelain Company from the dumortierite of this property.

A 3-inch pipeline of several hundred feet in length transmits the compressed air to the lower tunnel and surface workings. A string of pack mules packs up the mining supplies and brings down the ore.

The mine foreman acts both as mechanic and shift boss. After sharpening the steel he spends his time at the mine workings, with an eye and ear on the compressor. The reliability of this type of unit is shown by the fact that in over a year's operation it has given steady service with only a few cup leathers for repairs.

The dumortierite is a very slow drilling rock because of its combination of hardness and great toughness. A well-tempered machine-made bit dulls in three to five inches of drilling. It is also a difficult rock to break with sledge hammers.

Short tunnels and open cuts soon disclosed the fact that most of the large boulders were part of an unconsolidated surface overburden ten to twelve feet deep, but a few of the boulders were still partly encased in the schist formation, and one prospect tunnel encountered dumortierite in place in the schist.

To date the surface boulders have been the main source for the ore shipments, which now totals close to fifteen hundred tons. These boulders varied in size from a few pounds to a couple that furnished one hundred to two hundred tons each. Lately a main open cut has been started, with the idea of removing and sorting the overburden, and disclosing an area of the mineral-bearing schist to obtain an idea if the lenticular masses of dumortierite occur frequently enough in the schist to justify mining as an opencut over a considerable area.

At the present time the separation of shipping material is determined by the color and its "heft" checked occasionally by the use of the Jolly balance. By breaking with sledges and cobbing, any adhering schist is discarded and a very pure product made, having an average minimum gravity of 3.05 compared with 3.2 to 3.4 for the pure dumortierite. With the shipment of this pure product there will accumulate a much larger tonnage of second-class material in which the dumortierite occurs as narrow ribbons in schist or as mixed crystalline masses of dumortierite and quartz.

The possible utilization of this material is ably discussed under the section of this bulletin dealing with the ore dressing of durmortierite.

The development of this occurrence of dumortierite at a depth of about 200 feet below its outcrop is being carried on in a lower tunnel known as Tunnel No. 3. About 1,000 feet of work in this tunnel has disproved the theory that the dumortierite occurred in a possible vein formation along the hanging wall of a diabase dike encountered in the driving of the tunnel, but that it did occur in the schist formation on the dip of the schistosity below its outcrop, and in the same large lenticular masses of pure mineral as on the surface. Development work will be continued to determine if the dumortierite masses occur frequently enough over large enough areas at this depth to justify stoping operations.

PROSPECTING FOR DUMORTIERITE

Dumortierite is a silicate of aluminum of less common occurrence than the better known similar minerals, andalusite and sillimanite which are commonly known as "spark plug minerals" because of their use in that industry.

It differs from these minerals in that beside the elements aluminum and silicon, it also contains a small percentage of boron.

The natural occurrence of these three minerals is with highly siliceous igneous rocks. The main characteristics by which they might be detected in prospecting is their dull or greasy luster in massive form, their specific gravity which is higher than that of quartz, their hardness which is equal to that of quartz, and lastly, by their color which in andalusite and sillimanite is generally enough different from quartz or feldspar to excite curiosity, while in the case of dumortierite color is a distinctive characteristic. Dumortierite has color but is not limited to a single color. It varies from a deep blue to pink with shades between, as purple, lavender and lilac. These three minerals as a whole can be classed as uncommon minerals not easily identified without laboratory facilities.

The prospector who believes he has made a discovery of one of these so-called "spark plug minerals" should try to ascertain for himself if it be just an interesting occurrence of no commercial value or if there be a possibility of sufficient quantity to be profitably mined. He should send samples of the mineral and enclosing formations for determination to a State Mining Laboratory such as, for instance, is maintained by the State of Nevada at the Mackay School of Mines. There is no charge for such determinations, but the State expects in return as good a description of the mineral occurrence as the prospector can give in order to intelligently catalogue the mineral resources of the State.

The prospector naturally wants to know or should know the approximate value of these spark plug minerals and how nearly pure mineral the shipment must be in order to size up the value of his discovery or the effort he can put forth to retrace his steps to a mineral occurrence or favorable locality that he has in mind. The use of these minerals is too recent and restricted to have reached the point of a steady open market quotation. The Arizona Mining Journal has quoted andalusite at $50 per ton f. o. b. Philadelphia. This would correspond to approximately $30 a ton f. o. b. for points west of the Rocky Mountains. This tentative price for "spark plug" minerals in general is sufficient to indicate that it is not in the class with rare minerals sold in small lots and shipped by express, but more in the class with the higher priced nonmetallic minerals such as magnesite, sulphur, short fiber asbestos, or small size sheet mica.

At the present time a high percentage of purity is demanded. The mineral as it occurs or as it is mined, is apt to be contaminated with quartz intercrystallized or mechanically held in it, and the section of this bulletin dealing with the metallurgical treatment points out how serious this impurity is in high class refractory work. At the present time the purity of these minerals, such as dumortierite for instance, is judged commercially by its specific gravity. The pure mineral has a specific gravity of 3.2 to 3.4, and carload shipments are required to average close to 3.1 in gravity. With a more extended use of these minerals for less exacting requirements than that of spark plugs, it may be possible that much more impure mineral may be used but probably at a correspondingly lower price. As a whole, dumortierite and its kindred minerals offers, at the least, a very interesting additional chance of gain to the prospector searching for the more common metallic and nonmetallic minerals.

ORE DRESSING TESTS

By Walter S. Palmer
Professor of Metallurgy, Mackay School of Mines

From an ore testing standpoint there are at least six distinct types of dumortierite ore in the deposit in Humboldt Queen Canyon, and two types of ore have been sent to the Mackay School of Mines from the deposit at Lincoln Hill near Rochester. Both of the types found at Lincoln Hill are similar in general to ores found in Humboldt Queen Canyon.

These six types of ores can be described as follows:

Type 1. This type of ore is the high grade material which can be shipped directly as mined, with perhaps a little cobbing and hand sorting. All material coming in lump form and running over 3.05 in specific gravity is considered first-class ore.

Type 2. Consists of pieces composed of dumortierite surrounded or partly coated with coarse muscovite or with sericite schist.

Type 3. Consists of veins of dumortierite, some of which is distinctly crystalline in hand specimens, occurring in both sericite schist and in the material which has been described as type six.

Type 4. Consists of dumortierite closely associated and intergrown with quartz varying from fairly pure dumortierite to quartz only stained by dumortierite. Examination of thin sections of this quartz under the microscope shows fine needle like crystals of the dumortierite running through the quartz, giving it its color.

Type 5. Consists of dumortierite, both blue and pink varieties, with adalusite and some quartz and sericite.

Type 6. Consists chiefly of a mixture of quartz and andalusite with very little dumortierite.

ORE DRESSING TESTS

Since ore having a specific gravity of 3.05 is considered of shipping grade, such tests as have been made up to the present time on these ores have had for their object the producing of a concentrate running better than 3.05 gravity.

The associated minerals are dumortierite with a gravity of 3.26 to 3.42; andalusite, gravity 3.16 to 3.20; muscovite, gravity 2,86; sericite, gravity 2.82; and quartz, gravity 2.65. There are traces of pyrite in some of the ore which might have to be taken into account before an acceptable concentrate was produced. Several methods could be used to remove it from the concentrate.

High grade ore similar to Type 1 requires only a little hand sorting with perhaps a little cobbing to produce shipping ore.

Most of the ore of Type 2 can be raised to the required grade by simply grinding the lump ore on itself in a ball mill and washing. The dumortierite is quite tough while the sericite is quite soft and is easily crushed, while the coarse muscovite is dislodged from the dumortierite. It is understood that a little sericite or muscovite is not detrimental but is actually of some value in the final product when it is used for making spark plugs.

The first problem in the treatment of ores of Types 3 and 4 appears to be one of so crushing the ore as to liberate the dumortierite, or the dumortierite and andalusite, from the associated minerals of which quartz is the most important. The quartz and the dumortierite crystals are so intergrown and some of the dumortierite occurs in such fine hair-like crystals that it is practically impossible to crush the ore fine enough to liberate all of the dumortierite. Some idea as to the fineness of these crystals is given by the fact that whole networks of them will be composed of crystals less than 0.01 m.m. in diameter, some crystals having a diameter of only 0.001 m.m. Tyler Standard sieves of 300 mesh have an opening of 0.043 m.m. These fine crystals have produced two effects which are of importance in concentrating the ores; they tend to raise the gravity of the quartz grains in the crushed product and they also give an apparent color to the quartz, both of which complicate the operation of concentration to produce a clean dumortierite product.

Ores of Type 3 appear to separate into the individual minerals on crushing very much better than those of Type 4 and when such action results, a concentration of the dumortierite to a high gravity product is easily done. In some of the preliminary tests a concentrate running 3.26 has been made by gravity concentration and it is probable that even higher concentrates can be produced. A microscopic examination of the concentrate so produced shows that it consists quite largely of crystals of dumortierite free from adhering minerals. In fact the extent to which the dumortierite, andalusite, and other minerals can be physically separated, especially above 200 mesh in size, will indicate in general the extent to which the material can be successfully concentrated. At the present time only a few tests have been run on minus 200 mesh material. Fine material produced from Type 3 gave successful results but ore similar to Type 4 give inconclusive results on the minus 200 mesh material. More tests are to be run on this type of material.

No definite data is as yet available indicating what grade of concentrate will prove acceptable, and concentrates running 3.07 in gravity are now being experimented with by the Champion Company. If concentrate of this gravity can be used it will make possible the utilization of the low grade material which is found at Lincoln Hill near Rochester.

Tests were run using a high gravity pulp in an endeavor to separate a product running over 3.05 in gravity. Galena was used for this purpose because of its high gravity and the fact that we had enough of the mineral for the test. While it was possible to make some separation in this way and raise the product to 3.05 or better in gravity, it was decided that other and simpler methods could be used with equally good results.

Flotation has been tried on these ores but up to the present time the method is only partially successful in raising the grade of the final material. Reagents tried have removed fairly clean quartz but none have been found which would remove a clean dumortierite or, on the other hand, remove both the quartz and the material containing part quartz and part dumortierite.

Woolf[1] has found that there is little possibility of making a separation of the quartz and dumortierite by heating, quenching, and screening.

USES

Dumortierite is used with andalusite in the manufacture of porcelain for spark plugs. As has been stated the Champion Porcelain Company is shipping high grade dumortierite from its mine in Pershing County, Nevada, to the plant of the Champion Porcelain Company of Detroit, Michigan. The mineral forms a good basis for refractory material because of its high alumina content. It has important advantages (3) over sillimanite, andalusite, and cyanite. Dumortierite burns to a practically pure white product. Dr. J. A. Jeffery informed the writer that it increases the toughness and electrical resistivity of procelain and allows a greater temperature range in burning than does andalusite. It has a high fusion point, and porcelain made from a mixture of dumortierite and andalusite has a very low coefficient of expansion. Experimental ware made by the Champion Porcelain Company indicates that if sufficient dumortierite can be obtained its applications would multiply many fold. Greatly improved pyrometer tubes, chemical porcelain ware, and dishes have been made of it. The pyrometer tubes do not become porous or brittle after over a year's use in a kiln. The porcelain ware resists both mechanical shock and sudden changes in temperature much better than does the procelain now in general use. By using the proper mixture of andalusite and dumortierite a high grade refractory brick has been made by the Champion Company for use in their own kilns. Bricks made of dumortierite alone gradually swell and those made of only andalusite sag so that a proper mixture of the two yields a brick of just the right quality. The present known occurrence of commercial dumortierite is too limited to permit its employment in any field other than in the manufacture of spark plug porcelain.

Schaller (45) has suggested that dumortierite bearing rock might be used for ornamental stone if large enough pieces are obtainable. Certainly there is material in Pershing County, Nevada, which is valueless as porcelain ore but which might well be used for decorative purposes.

Schaller (45) and Knopf (23) both suggest a possible use of dumortierite as a semiprecious gem material. The quartz associated with dumortierite in Nevada often contains minute hair-like fibers of dumortierite which give the quartz a beautiful rose color, rendering it of gem quality.

USE OF DUMORTIERITE IN SPARK PLUGS

Due to the fact that the use of dumortierite as a commercial mineral is only carried out by one company, the Champion Porcelain Company of Detroit, who control the only known workable deposit, a brief description of its use and the making of spark plugs would probably be interesting to some readers of this bulletin.

The following description has been given the writer in conversation and in correspondence with Dr. J. A. Jeffery, President of the Champion Porcelain Company:

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[1] Tests made by J. A. Woolf, U. S. Bureau of Mines Rare and Precious Metals Experiment Station, Reno, Nevada.

The material as mined is hand sorted if necessary at the mine and then shipped to the Detroit plant of the Champion Porcelain Company. Upon arriving at the plant it is bedded in lots of 2,000 tons by a system of parallel rows, each carload being laid out in a long row parallel to and beside or above the previous carload. In drawing the material for use cuts are taken across the ends of the rows giving a good average lot of the material.

The coarse ore is first crushed in a jaw crusher to about one-half inch in size and is then crushed dry in a ball mill, using chrome steel balls, to minus sixteen mesh in size. It then passes over a magnetic separator to remove any iron from the ball mill and passes to a second ball mill where it is ground with sillimanite porcelain balls, and the mill is lined with sillimanite porcelain liners. Crushing is to such a fineness that all will pass a 100 mesh screen and 70% will pass 300 mesh. The material is then sampled and stored.

In preparing the body the ground dumortierite is mixed with ground andalusite, kaolin, and water and the griding continued in a special mill having a capacity of about two tons. Here the grinding is done in batches, and a charge will be ground for about seventeen hours. The slip or ground body will then pass a 300 mesh screen. The material then passes to filter presses where the excess water is removed. The cakes from the presses are stored in an aging cellar for ten days. This aging develops plasticity and gives time for each batch of material to be tested.

From the aging cellars the material passes through two pugging mills before being formed into the blanks from which the spark plugs are made. After thorough drying the blanks are turned down on special lathes and given their final form. The tolerance allowed is one three-thousandth of an inch. The cores are then glazed and are ready for burning.

The cores are burned in a continuous kiln 300 feet long, at a temperature of 2700 degrees Fahrenheit. It takes four days for the cores to pass through the kiln.

The cores are next stamped with the trade mark "Champion" or "Champion X" and then passed through an electrically heated furnace to fix the stamping, by burning the name into the glaze.

The cores are now ready to have the metal parts attached.

SAMPLES OF DUMORTIERITE SOLICITED

The Mackay School of Mines wishes to gather as complete a collection of specimens of dumortierite as possible and will very much appreciate the receipt of any samples the readers of this bulletin may have available and which they care to send in.

The School will reciprocate by supplying any information about dumortierite it may have to anyone requesting the same.

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MINERAL RESOURCES OF SOUTHERN NEVADA

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FOREWORD

The Thirty-fourth Session of the Nevada Legislature (1929) created the Nevada State Bureau of Mines. One of the most important functions of the Bureau is to make available, in the form of bulletins, reliable information about Nevada's mineral resources. This particular bulletin deals with the mineral resources and possibilities of Southern Nevada and the utilization of Boulder Dam power for the reduction of ores and the manufacture of products from these and other mineral substances.

While the Nevada State Bureau of Mines is separate and distinct from the Mackay School of Mines, the personnel of the two departments is the same, and it is from the records and personal investigations of the staff of the Mackay School of Mines that the data for this publication has been obtained.

This bulletin can be supplemented by F. C. Lincoln's "Mining Districts and Mineral Resources of Nevada" to great advantage. Lincoln's book contains excellent sketches of all of the mining districts in Nevada — history, geology, production and bibliography — and interested persons will find it authentic and reliable. The book is for sale by the Mackay School of Mines, Reno, Nevada, price $1.50 per copy, postpaid.

As a source of information on Boulder Dam power and matters pertaining thereto, see 70th Congress, Second Session, Senate Document No. 186, entitled "Colorado River Development."

Interested parties may obtain the names of owners of properties and deposits described in this bulletin by writing to the State Bureau of Mines, care Mackay School of Mines, Reno, Nevada.

Acknowledgment and thanks are due the following for their helpful cooperation:

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The officers, officials and employees of the many operating companies in Southern Nevada too numerous to mention by name, and the United States Geological Survey.

JOHN A. FULTON,
Director.

THE BOULDER CANYON PROJECT ACT

By George W. Malone, *State Engineer.*

The Boulder Canyon Project Act provides that the construction work may proceed if and when the "Colorado River Compact" shall be ratified by the seven States of the basin, or if it shall be ratified by six States and the water limitation as set down in the bill itself shall be accepted by the State of California through legislative action. This latter condition has now been brought about, and it is expected that actual construction work on the project will begin in the early part of 1930.

The project is located approximately thirty miles southeast of Las Vegas and twenty miles from a main line of a transcontinental railroad.

The construction of the branch railroad from the main transcontinental road to the dam site will start by October 15 this year, and the estimated time for completion is about 150 days.

The dam will be 550 feet high above the normal water surface, impounding 26,000,000 acre feet of water, with installed power plants capable of generating 1,000,000 horse power of electrical energy which, with an estimated load factor of 55%, will mean 550,000 "firm" horse power to be sold at the dam site.

The cost of the dam and power plant, including 4% interest during construction, is estimated at $121,900,000, and the bill provides that "firm" contracts must be had with the States, municipalities and private corporations to amortize the Government investment over a period of 50 years before construction may begin.

It is estimated under the present set-up that 3,600,000,000 kilowatt hours will be generated per year, which would mean a sale price of between 2 and 2½ mills per kilowatt hour at the switchboard in order to amortize the Government investment over a fifty-year period and maintain a reasonable reserve fund for emergencies, which would mean from $13 to $16.50 per horse power per year, which is the total cost that need be considered for use of the power in the vicinity of the project.

It is estimated that the transmission of electricity from the dam into the central power markets in Southern California, including necessary stand-by service, is estimated to cost from 1.6 to 2 mills per kilowatt hour additional.

Utah coal can be secured approximately 200 miles from the dam site at a very reasonable figure, and natural gas is available in Salt Lake City.

The Union Pacific Railroad transcontinental system passes within 20 miles of the project, a branch line being run direct to the dam, and the company has offered to cooperate in every possible way in the matter of freight rates to establish industries within the intermountain territory.

Sites for factories or reduction works of any kind can be secured practically without cost, taxes are low and labor conditions are good.

All of these items can be taken up and checked in detail, and the writer will be very glad to furnish detailed information upon inquiry.

There is a report printed as Senate Document No. 186, giving all details of the development of the Lower Colorado River, including power costs and full construction details of the Boulder Dam project. This report can be secured from any Senator, Congressman, or from the Bureau of Reclamation, Washington, D. C., direct.

The State of Nevada has requested permission of the Secretary of the Interior for an allotment of one-third of the power developed by the Boulder Dam project, and while the final allocation has not been made, we have every reason to expect that a liberal allocation of this power will be made to Nevada at cost at the switchboard. In this connection it will be arranged so any company desiring to secure a block of power for any purpose may be accommodated without undue delay.

COST TABLE NO. 2 — STRAIGHT LINE BASIS

Taken from Senate Document No. 186

At switchboard—Cost in mills per kilowatt hour	At power market (12 per cent line losses)	To States of Arizona and Nevada	To Government for special fund	Cost per horsepower year at switchboard
1.990	2.262	$672,800	....	$13.00
2.100	2.386	821,300	$247,500	13.72
2.200	2.500	956,300	472,500	14.38

The above table of costs, taken from Senate Document No. 186, shows that 1.99 mills at the switchboard will just return the Government investment with interest, and shows the effect on the reserve fund of prices up to 2.2 mills per kilowatt hour at the switchboard.

THE MINERAL RESOURCES OF SOUTHERN NEVADA

By JAY A. CARPENTER, *Professor of Mining, Mackay School of Mines.*

For the purpose of this survey, the term southern Nevada is used to designate approximately that part of Nevada south of the Mount Diablo base line, which in its east-west course, just south of the 38th parallel north, passes close to Goldfield and Pioche. This term is in distinction to central Nevada and northern Nevada, and besides applying simply to a geographical division of the State, it covers closely that portion whose railroad communication is to the south and whose mineral resources will be most vitally affected by the Boulder Canyon project.

The mineral resources of this section of the State have been excellently outlined by Mr. F. C. Lincoln in his comprehensive book, "Mining Districts and Mineral Resources of Nevada." This book is quite up-to-date, being published in 1923. Each mining district is described separately and completely; giving its location, history and production, along with the geology, the types of ores and ore bodies. In addition, the prominent mines and mining companies are mentioned, and a very detailed bibliography is given to aid further investigation.

The purpose of this description then is not to go into similar detail, but rather to supplement such detail by serving as an up-to-date quick-reference summary of these resources, with special emphasis upon their greater utilization when the Boulder Canyon project offers low-cost power to aid in their development and processing.

Capital in many lines of industry, attracted by the magnet of cheap power in the immediate vicinity of the power plants of the Boulder Canyon project, will wish to investigate the possibilities there for their particular industry.

One of the first questions arising will be that of whether or not the raw material necessary for their particular industry can be obtained near at hand.

The object of this summary is to give this information concerning the mineral resources of southern Nevada in a condensed form that can be easily and quickly consulted by interested capital without becoming involved in technical terms or detailed descriptions.

Another purpose of equal importance is to indicate to the prospector, the mining man, and the mining engineer the mineral resources and mining districts that are apt to be the most greatly benefited by the coming of cheap power, and conversely to indicate those minerals which, if found in large enough and pure enough deposits, would most attract capital having at hand a cheap source of power.

In gathering the information for this condensed economic summary of the mining resources of southern Nevada, a detailed inspection trip over the territory was made, much information was received from operators, engineers and prospectors, and many samples taken for the Mackay School of Mines Museum and for analyses.

Much study and thought also has been given to determining in advance, if possible, the most likely industries that will be established in southern Nevada due to the combination of cheap power and certain natural resources.

Since this summary will be consulted mainly by those interested in some particular mineral resource rather than some particular district, each mineral resource of importance is considered separately and given a prominent heading for the reader's convenience. The nonmetallic resources are placed first, followed by the metallic resources.

LIMESTONE AND DOLOMITE

Limestone formations are one of the most frequent occurring types of formations in the great area of sedimentary rocks that cover southern Nevada. Limestone is especially abundant in the immediate vicinity of the Union Pacific Railroad all the way across the State, including particularly the Las Vegas to Jean territory just north of the site of the power plant of the Boulder Canyon dam project.

The limestones vary in chemical composition from impure shaly limestones, to dolomitic limestones and limestones of high purity, and this latter class is quite abundant in the vicinity of the railroads.

In the past, neither the smelting industry nor the building industry has been large enough in southern Nevada to cause the erection of a number of small lime kilns with attending limestone quarries as was the case in central Nevada. However, with the growing demand for lime in construction work in southern California a lime quarry with small vertical kilns was opened up in 1912 alongside the railroad at Sloan, 17 miles south of Las Vegas. Being cheaply mined by open-bench method and lowered to the kilns alongside the railroad and there burned into a high grade lime, this limestone enterprise had sufficient advantages to develop into a stable producer. It is now the property of the U. S. Lime Products Corporation, and is equipped with two rotary kilns to handle about 200 tons of limestone a day.

The analysis of the limestone is given as:

SiO_2	0.65
Iron oxide and alumina	0.46
Magnesium carbonate	1.70
Lime, as carbonate	97.19

Recently a new limestone quarry has been opened up at Jean, Nevada, by the Blue Diamond Company of Los Angeles, and trial shipments of the limestone made to the company's large vertical kiln at Los Angeles.

In the limestone areas there are also beds of dolomite of high purity. One of these beds lies directly over the limestone bed that is being mined in the Sloan quarry. This dolomite is now being mined by the company, burned in two vertical kilns, and hydrated. The properties of this hydrate, sold as the "Boulder Canyon" brand, have been found to be so favorable that a third kiln is being added to supply the demand. The analysis of this dolomite is given as:

	Per Cent
Acid insoluble	0.21
Iron oxide and alumina	.44
Lime (CaO)	30.05
Magnesia (MgO)	21.80
Ignition loss	47.50

Besides cheap power, many chemical industries need also a cheap and abundant source of limestone to obtain the alkali, calcium oxide. (burned lime) and the gas, carbonic oxide (given off during the burning of limestone or dolomite).

It is fortunate that good sources of limestone and dolomite occur in close proximity to the future power plant at Black Canyon.

CEMENT-MAKING MATERIALS

Materials for making Portland cement such as pure and shaly limestone, shales and clays occur in great quantity alongside the Union Pacific Railroad. There has not been a sufficient use of cement in southern Nevada to justify the erection of a cement plant to compete against the Utah and southern California plants. The building of the high dam at Black Canyon, with subsequent industrial plants, might now justify the erection of such a plant.

Either of the lime quarries mentioned can find, or already have, a fair deposit of clay close by on the railroad, and the necessary gypsum for retarding can be obtained from producing mines close by.

GYPSUM

Gypsum occurs in great abundance in southern Nevada, not only along the Union Pacific Railroad but also close to the vicinity of Boulder Canyon along the old St. Thomas to Bitter Springs and Boulder Canyon wagon road.

The gypsum varies from impure gypsite and impure gypsum to thick beds of fairly pure selenite and pure gypsum. A high grade of gypsum has been mined close to the Union Pacific Railroad for over a decade to supply the plaster trade of southern California. After the World War four quarries were all producing and other deposits were being explored by pit or diamond drill. At the present time the Blue Diamond Company and the U. S. Gypsum Company are both operating at Arden, 12 miles southwesterly from Las Vegas.

MAGNESITE

Magnesite occurs in the vicinity of St. Thomas as large deposits of sedimentary magnesite. One of these sedimentary beds roughly parallels the railroad between St. Thomas and Moapa to the southwest and is about 4 to 6 miles away. This sedimentary bed is of surprising thickness and steeply enough tilted to offer an easy attack from the gulches for open-cut mining. It is close enough to the railroad for an easily constructed short branch line.

Another occurrence of similar magnesite lies about 17 miles southeast of St. Thomas and across the Virgin River. This particular deposit occurs on the surface of low hills and sides of gulches, which is favorable for cheap mining.

In both localities the tonnage is immense but, as in the case of other sedimentary magnesites, it is not a pure magnesite as it contains both calcium oxide and silica in a greater percentage than is now considered commercial.

The magnesite to the southwest of the railroad breaks with a conchoidal fracture, but when placed in water resembles a clay in the manner in which it forms a colloidal slime or pulp. In fact, the first use of this magnesite was probably by the Indian for his clay for pottery making, as the remnants of charcoal fires and pottery indicate this. The only shipments made to date of this magnesite were those to pottery makers as a pottery clay, and the shipping spur was named Kaolin.

The peculiar physical properties of this magnesite, coupled with its large and easily mined tonnage close to the railroad, taken in connection with the possibilities of cheap electric power from the Boulder Dam project, offers an interesting chemical and industrial problem.

A description of this occurrence of magnesite, with analyses, can be found in the U. S. G. S. Bulletin No. 798 entitled "Geology of the Muddy Mountains." Since this bed of magnesite outcrops in many gulches over a distance of several miles, there is a possibility that if the outcrops be carefully sampled and drilled, that certain sections of the outcrop might be found to be much freer of impurities than the well-known outcrop near Kaolin siding.

The magnesite to the southeast of St. Thomas is a harder rock in comparison with that just mentioned, and breaks down in water much less readily. It contains, as a whole, less impurities in the magnesite itself, but the closer association with dolomitic limestone and beds of clay would make very careful mining and sorting necessary to maintain a product close to the present-day required analysis. The greater distance from the railroad is also an additional handicap.

It has been reported that there are sedimentary beds of magnesite in the vicinity of the West End borax mine, which is only 10 miles northwesterly from Boulder Canyon. This I was not able to confirm.

There is a good possibility that a body of pure magnesite ore might be found in the southern end of Nevada if a vigorous search by prospectors was inaugurated by the simple expedient of a bona fide offer of a cash purchase of the discovery. The great area of dolomitic limestones and dolomites is a likely prospecting ground, in view of the beds of sedimentary magnesite already found.

As an illustration, within the last two years there has been discovered 30 miles northeast of Luning, which is near the new United States Navy munition depot at Hawthorne, a deposit of great tonnage of very pure brucite, the hydrate of magnesium. This deposit outcrops prominently on a granite and dolomite contact and was walked over for years by prospectors in search of precious metal ores.

With the advent of the airplane, and the continued search for and extended use of lightweight alloys in all power generating machinery, there is an expanding use of the lightweight metals such as aluminum and magnesium. Commercial deposits of aluminum and magnesium ores in the vicinity of cheap electric power at Black Canyon will surely be of future value, and will eventually attract manufacturing capital to them.

GLASS AND FOUNDRY SANDS

Sandstone beds of great thickness occur in southern Nevada, especially in the vicinity of the Valley of Fire. It is a deep red fantastically eroded sandstone that gives the Valley of Fire its name.

Within a few miles of the Union Pacific Railroad from Las Vegas to Moapa, also on the branch line from Moapa to St. Thomas, and probably more extensive than this, are beds of sandstone of a creamy white or slightly yellowish color composed almost entirely of pure quartz grains of uniform size.

The growing glass and foundry industries in southern California have caused, in the last two to four years, a search for suitable sands in southern Nevada to compete with imported Belgian sand, sands from southern California and other localities in the United States.

As a result, several trial shipments have been made, and at the present time one pit is being operated four miles west from a spur on the railroad south of Overton. A shallow overburden is removed, the sandstone is loosened by explosives, pulled by a drag line into auto trucks, and hauled to the railroad where it is disintegrated, screened and washed before shipment. A second pit or open cut is being opened up in the same vicinity but about four miles farther from the railroad than the present operating pit, with the ambitious idea of a future 10-mile branch line from the railroad.

At present this industry is on a close margin basis, with a chance to expand if sands for special purposes are found and if favorable tariff adjustments come about along with cheap electric power. A systematic search might disclose beds of sandstone equal to the high-priced sand of Ottawa, Illinois.

SAND, GRAVEL AND ROCK FOR CONSTRUCTION PURPOSES

There are beds of sand and gravel near the railroads, highways and towns, but generally they are covered with surface soil and somewhat mixed with it. There are pits all along the gravelled State highway, known as the Arrowhead Trail, crossing the southern end of Nevada. At present there is no large pit producing high-class washed sand and gravel, but sufficient demand will bring this about. Las Vegas wash, lying approximately between Las Vegas and Black Canyon, is an old stream-bed area that can probably furnish an unlimited source of sand and gravel for concrete work.

There are both igneous and sedimentary rocks close to the railroad that can be quarried for large scale concrete work.

The dolomite in the high cliff now exposed above the railroad at Sloan, in the U. S. Lime Products quarry, gives an ultimate compression test in 3-inch cubes of around 12,000 pounds per square inch.

This subject of sand, gravel and rock will be thoroughly investigated by the United States Government before building the Black Canyon dam, and at wherever points these materials are obtained there also will be developed sources for future use.

BAUXITE, ALUNITE, ALUMS AND CLAYS

Bauxite is the aluminum mineral that is commercially used for the production of the metal aluminum in connection with cheap electric power. Unlike in past years, the discovery of a bauxite deposit at the present time in southern Nevada would be of commercial value in view of the coming cheap electric power from the Boulder Canyon project. In past years discoveries of bauxite have been claimed, but no definite records kept, and at the present time there is no deposit on which development work is being done.

Alunite, the hydrous aluminum sulphate containing soda or potash, is found in southern Nevada. It occurs in some quantity just over

Railroad Pass, 20 miles out on the road from Las Vegas to Black Canyon. As alunite was one of the mineral associates of the rich gold ores at Goldfield, quite extensive underground development work was at one time carried on at this Las Vegas deposit in the hope of finding gold ores in paying quantities.

Since it was mainly sodium instead of potassium in this alunite, it did not compare favorably with the alunite of Marysville, Utah, which, during the war, was calcined to recover potassium sulphate with aluminum oxide as a by-product.

Water soluble alums also occur in southern Nevada. About 9 miles beyond Railroad Pass on the road to Black Canyon and then 3 miles southerly, there is a most interesting occurrence of soluble alum salts, with some sulphur, in weathered igneous rocks in two belts 300 to 600 feet wide, having an easterly and westerly strike.

The alum salts, at least over the surface and for a distance down to 50 feet, occur in great abundance in the crevices of the finely disintegrated rock. A shaft bottom discloses considerable pyrite in the firmer rock and the surface weathering of this rock evidently gives the alums.

Clays occur in considerable abundance in southern Nevada. Certain deposits on the Tonopah and Tidewater Railroad are being worked quite extensively for use in the oil industry for oil clarification. None of those along the Union Pacific have as yet been found suitable and sold for that purpose, or for use in making China clays or refractory brick. In fact, no use has yet been made of them for even making common brick. Considering the high cost of lumber and cement at Las Vegas there should be a fair chance of success for a well-located brick plant, as common brick is an ideal building material for a warm desert country.

At present there is considerable experimental work being carried on with the idea of the acid treatment of clays to free the aluminum oxide as a source of aluminum, which process is of interest in connection with these clay deposits and cheap electric power.

BORATES

Borax ores in the form of colemanite deposits occur in commercial quantities in southern Nevada in close proximity to Boulder Canyon. Both the Pacific Coast Borax Company and the American Borax Company at one time held or worked deposits here, but the premier deposit of colemanite in this vicinity, and that of the Pacific Coast also, was purchased and put on steady production by the West End Chemical Company. It is now handicapped by recent low prices for borax products, due to increased production from Searles Lake brines and the Kern County water soluble borax mineral, kernite.

In this connection, there are between Virgin Valley and Black Canyon certain bitter springs, sink holes, and old lake beds that suggest their geological study with the idea of drilling test holes in search of beds of soluble salts. One of these lake beds, 10 miles from the railroad on the West End Chemical Company's trucking road, has a remarkably extensive surface deposit of selenite. A 50-foot shaft is still in this crystal selenite, pure except for about 8% of admixed clays.

SALT

Beds of rock salt occur in the lower end of Virgin Valley below St. Thomas. Those close to the Colorado River may eventually be flooded by the impounded waters of the Black Canyon dam. The deposit of the best commercial value at present is just four miles south of St. Thomas on the west side of the valley, just above the projected shore line of the future lake that may cover St. Thomas and extend up to Kaolin near the large magnesite deposits.

This glimpse into the future of this salt deposit on the shores of a large inland lake is particularly interesting when one visits the salt caves in it that bear the marks and evidence of the prehistoric mining of this salt by the pre-Pueblo Indians, the remains of whose villages on the east side of the valley near St. Thomas are of keen anthropological interest.

This deposit is a large bed of salt of great thickness and of high purity except for the inclusion of a small and varying amount of red clay. Large specimens can be secured of the clearness of plate glass. It is being worked on a close margin by means of an adit and a room-and-pillar method of mining. The salt, after crushing and washing, is shipped direct to the Los Angeles market.

Another deposit of large size lies beyond the Bitter Springs Hill, southwesterly from this deposit, and there is a probability of other deposits still closer to Boulder Canyon.

These salt beds may be of much greater economic importance with the coming of low-cost electricity, for the reason that the electrolysis of salt solutions to obtain sodium hydrate and chlorine is a rapidly expanding chemical industry.

SULPHUR AND PYRITES

Both sulphur and massive iron pyrites are important as a source of sulphuric acid, which acid is the most used of all acids in chemical industries. There are no known deposits of sulphur in southern Nevada. There are quartz veins carrying a very high percentage of iron pyrites in the Key West and Bunkerville districts, but no massive pyrite reported. There is a mixed sodium and calcium sulphate deposit of probably an immense tonnage six miles south of St. Thomas.

BARITE

Barite has been reported at Goodsprings. The recent use of the formerly useless colored barite for oil well heavy specific gravity "mud" should stimulate prospecting for off-color barite along the Union Pacific Railroad.

FELDSPAR

A feldspar quarry has recently been opened up just within Nevada, six miles from the railroad at Nipton, California. This feldspar deposit is in granite. It is about 200 feet wide and exposed for considerable length.

OTHER NONMETALLICS

Other nonmetallics such as phosphates, graphite, asbestos, mica, talc and fluorspar have not been reported as yet in any promising quantity in the southern end of Nevada.

NITRATES, AND FIXATION OF NITROGEN FROM THE AIR

Commercial deposits of nitrates are unknown in southern Nevada. Small local impure beds probably occur in the neighborhood of Death Valley.

The present source of nitrates, outside of Chile, is not from natural deposits of nitrates, but by either their recovery from distillation products of coal or from the fixation of nitrogen from the air. This latter method has been made commercially possible through the use of *cheap electric power* for air liquefaction to obtain nitrogen and for the electrolysis of water to obtain hydrogen, and from the two to obtain ammonia.

The recovery from coal products is the prevailing method in Belgium, Germany and in our eastern States, but the plants for the fixation of atmospheric nitrogen exist where electric power is available at a cost of 2 to 2½ mills per kilowatt hour or less. This is particularly true of Norway, where new plants are going in at the present time. A large plant is in course of erection by the Consolidated Mining and Smelting Company of Canada, in British Columbia, for the purpose of manufacturing fertilizers. It will use 33,000 horse power in the fixation of nitrogen from the air as ammonia.

With the growing agricultural and chemical industries on the Pacific Coast and with low-cost power at the Black Canyon power plant without transmission costs, the future prospects of nitrogen fixation plants and electrochemical and metallurgical plants in Nevada near the power plant should be bright enough to cause their careful investigation by interested capital. This listing of the Nevada mineral resources close by is made with the hope of aiding such investigations.

These plants may not be erected even in the first decade following the completion of the power plants, but the Boulder Canyon project, like the Panama Canal, is not only to serve this generation but the generations to follow.

Farsighted corporations will obtain a foothold as soon as practicable. The excess or "dump" power of the early years of operation of the power plant may be a deciding factor in the early establishment of such industries.

Although the maximum year-round steady supply of power for over a long period of years from the proposed power plants can be safely set at only 550,000 horse power of electric energy, the power plant is to have sufficient units to generate a million horse power. Until the upper basin States begin to utilize a large share of the Colorado River basin waters allotted to them, and until auxiliary dams are erected below the Black Canyon dam to supply the wide variation in seasonal demand for irrigating water, until then, it is estimated that the power plants will generate a great excess of power over the 550,000 firm horse power. The sale of this firm horse power at 2 to 2.5 mills per kilowatt hour at the power plants, along with other sources of revenue, is estimated to produce sufficient revenue to pay all operating costs, along with interest and amortization of the investment.

Under this condition it is a matter of interesting speculation as yet as to how low a figure this excess or "dump" power could be contracted for.

To visualize the future need for such industries I quote here from an address of John E. Teeple, of New York, to the American Chemical Society, as printed in *Industrial and Engineering Chemistry* of October, 1927. Mr. Teeple was awarded the Perkin Medal of 1927 as a "most distinguished chemist," mainly because of his close connection with the successful recovery of potash at Searles Lake.

He states: "We can predict with certainty that in the future there will be a tremendous growth of the chemical process of the fixation of nitrogen and of the further chemical process of making phosphate rock available for plant food. Today we are using only about 1,500,000 tons of nitrogen a year. Most of us shall probably live to see the day when 20,000,000 to 30,000,000 tons of nitrogen are taken from the air every year by some nitrogen fixation method."

Also, he states: "Chemical progress, however, is developing many other tools more effective and more convenient than acid and alkali. I refer to such agents as catalysts, reactions at high pressure, and reactions at high temperatures such as the electric furnace. By means of these new tools we are just opening the field of large scale synthesis."

Further on in this scholarly address on "Economic Factors in Chemical Industry," he states: "The five important factors are raw material, power, markets, technically trained personnel, and 'educated' money. Any country can have a well-developed chemical industry if it has the will to do so and takes the necessary measures. Italy is not particularly gifted by nature with any of the five important economic factors," yet she "is a good example of a country that seems to have deliberately set about building a chemical industry, and she has made a remarkable success."

All the above is pertinent to Nevada's opportunity if she avails herself of her share of the power from the Boulder Canyon project. Her lands and mineral resources will adjoin the dam and power plant, and her transcontinental railroad will have a branch line to the power plant connecting the future industries located there with the raw resources and markets of the Pacific Coast.

COAL. OIL AND NATURAL GAS

Southern Nevada, like Italy, is lacking fuel resources of her own. No worthwhile discoveries of coal, oil or natural gas have been made nor, judging from the past quarter of a century, does there appear to be much hope that there will be. The best substitute is low-cost electricity supplied to electric furnaces and electric heating devices.

Excellent low-cost coal can be purchased from large producing mines in Utah less than 300 miles from Black Canyon, and within the same distance both California crude oil and natural gas are available. Natural gas is now being piped long distances, as from Wyoming into Salt Lake City and from near Bakersfield into San Francisco.

METALLICS

Iron Ores

There are no iron ore deposits in southern Nevada of sufficient purity and size to be of commercial value. Several occurrences of iron ore have been reported, but upon investigation these occurrences proved to be either only a heavily iron-stained siliceous rock, as in the neighborhood of Boulder Canyon, or quite a pure iron oxide, but very limited in quantity, as in the mountains 10 miles northeast of Las Vegas.

There is a reported occurrence of a large body of iron ore on the Utah-Nevada line, 40 miles from the railroad. There are large bodies of high-purity iron ore close to southern Nevada in both Utah and California.

Manganese Ores

Many carloads of manganese ore were shipped from Las Vegas during war times. The producing mines were only 17 miles southeasterly from Las Vegas.

The grade of ore shipped averaged over 35% manganese, with a very low iron content and quite a high silica content of 9% to 15%. The ore contained also 1% to 2% lead and 1 to 2 ounces of silver.

There were two producing companies holding adjacent claims on practically the same outcrop. The claims were located in 1917, but a very limited amount of development work has been accomplished, as all early efforts were centered on shipping, followed by a complete shutdown after the war.

The ore is 8 to 19 feet thick, with a flat pitch and a well-defined strong hanging wall, all of which is conducive to cheap mining. The workings resemble a coal mine in appearance and method of mining.

The unfavorable feature during the time it was being mined was the necessity of sorting the ore to better than a 35% manganese or 55% manganese dioxide content in order to show any profit after shipping to eastern points. This sorting, with rejection of the greater part of the ore, would prohibit its mining at the present time.

The faces as now exposed will probably average 20% in manganese. Due to lack of development there is a dearth of positive ore tonnage, but there is a large probable tonnage of a half million tons, and an excellent opportunity for churn drilling beyond present exposures to increase this tonnage.

At the present time there is no process adaptable for the economic recovery of manganese, at present prices, from low grade siliceous ore of this kind, but experimental work is being carried on by private and Government research laboratories.

The type of experimental work that best applies to this particular ore is that of reduction in the electric furnace, due to the closeness of the deposit to the future power plant at Black Rock Canyon, only 10 miles away. This source of cheap power and the size of the ore deposit justify experimental work on the ore.

While production was limited to the one locality at the Three Kids and International mines, other discoveries and locations were made in the same vicinity, and a deep well drilled for Senator Miller about 5 miles westerly was reported to have gone through a thick bed of similar "black ore" at 600 feet in depth. With the closing of the producing mines interest in manganese died out, leaving an unproven territory worthy of prospecting and developing at some future time when the present ore bodies can be profitably treated.

Outside of this one district no other discoveries of manganese ore have been reported in southern Nevada, but across the Colorado River in the Bill Williams River country engineers have reported millions of tons of 6% manganese ore.

Nickel Ore

The one occurrence of nickel reported in southern Nevada is in the copper-nickel-platinum ore of the Key West mine, about 15 miles south of Bunkerville and east of the Virgin Valley. Theoretically the nickel is in sufficient quantity to be a valuable constituent in the ore, but so far it has been a handicap due to the penalty imposed upon it in the copper concentrate, and also to the absence of any western treatment plant if the nickel mineral be separated into a concentrate by itself.

Tungsten Ore

No tungsten ore has been reported from the southern end of the State. During the World War there were operating tungsten mines as far south in the State as Mina on the western and Pioche on the eastern side of the State. The largest producer of tungsten concentrate in the United States at present is at Mill City, in Pershing County, and the concentrates must be shipped east to Niagara Falls where they are reduced in electric furnaces. The present rising price for tungsten is resulting in new development work at old properties.

Vanadium Ores

The occurrence of vanadium minerals has been reported from several mining districts in the southern end of Nevada. These minerals are usually of secondary importance to other minerals in the same ore, but at the Ewing mine and in its neighborhood, which is about nine miles westerly from Goodsprings and close to the State line, the vanadium minerals occur in sufficient quantity to be considered of primary importance, and the ore is termed a vanadium ore.

The vanadium minerals are vanadinite and descloizite, which are combinations of lead and lead and zinc with vanadium, and these minerals occur along with other lead and zinc minerals, both sulphides and carbonates, in a limestone gangue.

The metallurgical problems and possibilities of this particular ore were investigated by the United States Bureau of Mines. (Reference: Reports of Investigations. Serial No. 2433.)

The outlook has not been bright enough to justify an exploration campaign to determine how large a tonnage could be developed of a concentrating grade of 2.5% vanadium oxide. Tests indicated that such a grade of ore could be concentrated with a 70% recovery to a 10% content, that would in turn be of smelting grade. The cost of shipping such a concentrate to the east, or to Germany, coupled with the exacting terms of settlement on such a difficult concentrate to treat, gives little inducement for its production at present.

Such concentrate is usually smelted in electric furnaces, and with the advent of cheap power in Southern Nevada for mining, milling and smelting, the possibility of an increased selling price for vanadium products might result, at some time, in a brisk development campaign to determine the vanadium resources of this district.

Cobalt Ores

Cobalt has been reported as found both in the Goodsprings and Key West districts in minor quantities associated with other metals. Shipments of cobalt ore have been made from Goodsprings.

Platinum

The presence of platinum in mining districts is so often heralded but so seldom proven to be there. Two authentic occurrences of platinum have been found in the southern end of Nevada. The Boss mine at Goodsprings made shipments of a gold-platinum-palladium ore of high value, but a sufficient amount of the ore could not be found to make it a profitable mining venture.

In the Key West mine the copper and nickel bearing ore contains platinum, but not in sufficient quantity to obtain pay for the platinum under present smelting contracts.

Copper Ores

From a copper standpoint, southern Nevada lies between the big copper producing district of Ely, Nevada, to the north, and like districts in Arizona, but apparently lacking in similar large low grade copper deposits itself. It is true that copper is found in several mining districts of southern Nevada associated with other metals, but usually of minor economic importance itself. In four districts, however, the copper content of the ores is an important factor.

The Searchlight district has produced a half million pounds of copper, due mainly to the copper occurring in gold ores. With the possibility of higher priced copper and cheap power, the properties where copper predominates over the gold in value may be worthy of considerable exploration work.

The Yellow Pine district has produced, mostly during the war period, over three million pounds of copper from small oxidized ore bodies in limestone. The abundant deposits of lead and zinc ores in this district carry practically no copper. The Pioche district, including the Bristol district, produced over five million pounds of copper, but in this case the copper occurs along with lead and silver ores.

The Key West or Copper King district south of Bunkerville offers the best possibilities of becoming a copper producing district. The combination of copper sulphide ores occurring in an area of granitic rocks with intrusive basic rocks is a favorable one.

Besides copper, the ores contain nickel, cobalt and platinum in quantities sufficient to make the gross value of the ore most attractive when figured upon the selling price of the separate metals.

However, the metallurgical and economical problem of separating and marketing the metal contents profitably is still unsolved. This holds back the exploration of the several good surface showings in the district. The one mine, the Key West, that has been developed to over 200 feet in depth indicates the possibilities of large sized ore bodies in this district.

The Eldorado district, which lies between Searchlight and Black Canyon, is worthy of mention as a possible future producer of copper ores. The district is credited with a gold production of over $2,000,000 under very adverse circumstances as to location and transportation. The geological formations are favorable for base metal ore bodies, and there are many undeveloped prospects showing sulphides of copper, lead and zinc.

Black Canyon is only 18 miles to the north, and with a branch railroad extended to it and a power plant there, the base metal ores of the Eldorado district may interest capital.

Zinc and Lead Ore

Zinc and lead ores are here considered together, because in southern Nevada they occur generally in the same districts. One marked exception is the Groom mine, 100 miles north of Las Vegas, that, to its present depth of mining, is shipping a lead-silver ore free of zinc. The Bristol or Jack Rabbit district, near Pioche, has been a consistent producer of lead-silver-copper ore with a negligible amount of zinc, and in 1928 was the largest producer of lead in Nevada.

Pioche has been known as a lead camp. The surface ores worked in the seventies were very rich gold and silver ores, giving a production totalling many millons of dollars. Production of the base ores did not start until after 1900.

From 1900 to after the war a million tons of lead ores, mainly oxidized, were shipped to Utah smelters. The average grade of this ore was under $10, but the chemical composition was quite ideal for smelting. During the war oxidized zinc ores were also shipped. The rapid development in recent years of differential flotation has made it possible to mine the mixed sulphide ores of lead and zinc. In 1928 Pioche was the largest producer of zinc in the State, and the camp is quite active. The milling and smelting of the ore is carried out at present mainly in Utah. Cheap electric power in the future might be quite a determining factor in extending mining and milling operations in the camp.

The Goodsprings, Yellow Pine, or Potosi district at Goodsprings, has been, since 1900, the premier zinc producing district of Nevada, reaching a peak production of over 20,000,000 pounds of zinc a year during World War times, with about a third as much lead. Outside of the sulphide ore bodies of the Potosi mine, the ore is mainly mixed lead and zinc carbonate ore. The camp has been at a low ebb for over a year now, but the possibilities of differential flotation followed by the conversion of the zinc concentrates to marketable zinc oxide right on the ground has resulted in the resampling of most of the mines. The main expense in the treatment of the carbonate concentrate will be for fuel, and cheap electric power will probably not be a determining factor.

The Potosi mine has large reserves of low grade sulphide ores, mainly zinc. The newer combined acid and electrolytic method of treating zinc concentrates, depending largely upon a low cost for electric power, is applicable to sulphide concentrate such as the Potosi would produce, and that the Tybo mine north of Tonopah is now producing and shipping to Idaho for treatment.

CONCLUSION

It is apparent that low-cost power will stimulate the development of the mineral resources of southern Nevada, and conversely these mineral resources will furnish the necessary raw materials for many future industries attracted to Nevada by the low-cost power from the Boulder Canyon project.

LETTER TO GEORGE W. MALONE Re CHEMICAL INDUSTRIES AT BOULDER DAM

RENO, NEVADA, September 25, 1929.

MR. GEORGE W. MALONE, *State Engineer, Carson City, Nevada.*

DEAR MR. MALONE: In compliance with your request following our discussion of chemical industries that might reasonably be expected to be interested in power developed from the Boulder Dam project, I should like to mention two in particular, viz, first the fixation of atmospheric nitrogen through oxidation of ammonia obtained by direct union of nitrogen and hydrogen, and, second, the reduction of certain ores.

The danger and expense connected with the transportation of large quantities of high explosives from eastern factories to the Hawthorne depot will undoubtedly prompt investigations into the possibility of the manufacture of certain of them, at least, in the west. Since nitric acid is the basic substance used in their preparation, the location of a factory might easily be determined by the possibility of obtaining cheap nitric acid. There appears to be no doubt that its synthesis from ammonia obtained by the fixation of atmospheric nitrogen using the Haber principle of direct union of hydrogen and nitrogen, will become the leading method of manufacture. According to recent figures given in *Industrial Engineering Chemistry* 19, 789-794 (1927) it can already be obtained more cheaply in this way than from Chili saltpeter. The raw materials used consist of nitrogen, oxygen and hydrogen. The first two are best obtained from the atmosphere. While hydrogen may be obtained by several different methods, it is claimed by many that with reasonably cheap electric power it can be produced economically by the electrolysis of water. If this be true, it should be possible to manufacture such explosives as T. N. T. and nitrocelulose, as well as many of the war gases, by utilization of electric power developed at Boulder Dam.

The large deposits of nearly pure sodium chloride (halite) found in southern Nevada would permit of a further decrease in the cost of the hydrogen by electrolysis of its solution rather than of water, since two valuable by-products, sodium hydroxide and chlorine, are obtained. The extensive use of sodium hydroxide in the refining of petroleum and in connection with the fruit industry of California should provide a market for it, and since the chlorine industry is developing along the line of its production by this process, it is evident that a sufficient outlet for the chlorine would insure the practicability of the production of hydrogen by the electrolytic process. In view of the wide variety of uses chlorine has, and the fact that it forms an important material in the manufacture of war gases in addition to the possibilities it offers in the metallurgical industry, makes it very unlikely that its disposition would be difficult. The conditions, therefore, appear to be very favorable for the manufacture of many of the explosives handled at the Hawthorne storage plant by use of electric power developed at Boulder Dam.

The probable amount of power used for this purpose, calculated from that reported for the manufacture of ammonium sulphate at the Trail Smelter of the Consolidated Mines and Smelter Company of Canada, would be about 400 continuous horse power per ton of nitric acid per day. One ton of nitric acid would be required for the manufacture of one to one and a half tons of explosives. On the assumption that a ten-ton plant would be required, about 4,000 horse power would be used.

A second electrochemical industry which should receive an impetus from the power developed at Boulder Dam is that connected with the extraction and preparation of metals possessing a high degree of purity. With the increased demand for metals of this type have come new methods for their extraction and reduction. The last few years have witnessed the development and industrial use of the electric furnace for the production of zinc, as well as a number of the rarer metals. Reducing gases, of which hydrogen is the most efficient, are also being used to some extent to replace the solid fuels. Investigations going on in our laboratory point to the possible use of chlorine as an extraction agent for tungsten. Hydrogen has long been used as a reducing agent for it. Both these gases should be economically obtained by electrolysis; as I have indicated above. While it would be difficult to predict to what extent electric power will be used for these purposes, it seems reasonable to suppose that it will not be inconsiderable in view of the quantities of those metals produced in Nevada and neighboring States.

Very sincerely yours,

George W. Sears,
Head of the Department of Chemistry,
University of Nevada.

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THE UNDERGROUND GEOLOGY OF THE WESTERN PART OF THE TONOPAH MINING DISTRICT, NEVADA

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UNDERGROUND GEOLOGY OF THE WESTERN PART OF THE TONOPAH MINING DISTRICT, NEVADA[1]

By THOMAS B. NOLAN

INTRODUCTION

Early in 1929 the Nevada State Legislature appropriated $10,000 to be expended on geologic and topographic work in cooperation with the United States Geological Survey during the biennium 1929–1930. The Nevada Mine Operators Association recommended that one of the projects undertaken under this fund be a geologic resurvey of the Tonopah mining district, in Nye and Esmeralda Counties. The writer was assigned to this project and carried on field work from July 11 to October 25, 1929. During this period the readily accessible workings of the following mines in the western half of the district were examined: Tonopah Extension Mines, Inc. (Victor, Cash Boy, McKane, Extension No. 1, and Extension No. 2 shafts); West End Mining Co. and the associated West End Extension Co. and Tonopah 76 Co. (West End and Ohio shafts); MacNamara Mining Co. (MacNamara shaft); Tonopah Midway Mining Co. (New Midway and Old Midway shafts); Jim Butler Mining Co. (Wandering Boy, Fraction No. 1, and Fraction No. 2 shafts); Tonopah Mining Co. of Nevada (Sand Grass, Red Plume, and the country west of the Mizpah and Silver Top shafts); and Keystone Mining Co. shaft.

The present report is based upon this examination and summarizes the preliminary conclusions reached. These conclusions are subject to revision after the workings in the eastern half of the district are examined—a task which it is hoped will be accomplished during the field season of 1930. It is planned that the final report on the district, which will include the geologic maps, will be published as a professional paper of the United States Geological Survey.

The writer desires to acknowledge his appreciation of the whole-hearted cooperation shown by the officials of all the companies and his indebtedness to them for the details of the geology in workings not now accessible. He also wishes to acknowledge the able assistance of Ian Campbell and J. W. Vanderwilt, and the helpful suggestions and criticisms made by H. G. Ferguson, G. F. Loughlin, and W. C. Mendenhall during their several brief visits to the district. Mr. Campbell has also provided for this report the results of his microscopic study of the rock specimens collected.

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[1] Published by permission of the Director, U. S. Geological Survey.

PREVIOUS GEOLOGIC WORK

By far the greater part of the geologic work in Tonopah represented by published reports has been done by J. E. Spurr. His first work there was done in 1902 and 1903, and is covered by Professional Paper 42 of the U. S. Geological Survey, published in 1905. He also visited the district in 1908 to examine the West End and MacNamara mines professionally, and returned in 1910 to study the Belmont, Montana, Midway, and Tonopah Mining Co. properties. He was made an officer of the Tonopah Mining Co. in 1912 and remained in Tonopah for more than three years. Two publications represent the investigations made during the two later visits.[1] The following extract from the second of these papers summarizes his final conception of the geology:

> At Tonopah the oldest rock is a trachyte flow highly altered to quartz, sericite, and adularia. The lower part of this flow is a fine flow-banded glassy trachyte. The main body of the trachyte contains the oldest and by far the most important group of mineral veins; the glassy trachyte appears practically barren.
>
> Stresses subsequent to the trachyte extrusion produced horizontal fissuring near the zone of transition between the main body of trachyte and its glassy lower portion; and along here an andesite (Sandgrass andesite) intrusion penetrated. After renewed fissuring along the same zone, a glassy trachy-alaskitic intrusion (Montana breccia), very full of inclusions, took place, usually following along immediately above the andesite. Subsequent movement reopened this line of weakness, and a second trachy-alaskitic intrusion came in—the West End rhyolite sheet—which penetrated along a fissure usually lying immediately above the Montana breccia. At a subsequent epoch came an eruption of andesite (Midway andesite) as a surface flow; at a still later epoch there was a series of rhyolitic and alaskitic surface flows and intrusions, of which the most important in the mine workings is a great intrusive mass called the Tonopah rhyolite.
>
> The principal veins were formed after the trachyte eruption and before the Sandgrass andesite-Montana breccia-West End rhyolite intrusions. They are quartz veins carrying silver and gold. A second set of veins was formed after the West End rhyolite intrusion and before the Midway andesite eruption. This second set is divided into four successive groups—A, large typically barren quartz veins; B, tungsten-bearing veins; C, mixed quartz and adularia veins, typically barren; D, productive veins like those of the first set following the trachyte. A third set of veins was formed after the Tonopah rhyolite intrusion. They are quartz veins carrying occasional lead, zinc and copper sulphides.
>
> All these veins formed at shallow depths, and the different types are held to represent various stages of temperature. The first-period veins represent the normal shallow-seated type, and followed the trachyte eruption; the second-period B veins probably represent an abnormally

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[1] Report on the geology of the property of the Montana-Tonopah Mining Co., Tonopah, Nevada, published by the company, 1910; Ore deposition at Tonopah, Nevada; Econ. Geology, vol. 10, pp. 713–769, 1915.

intense shortly sustained temperature, following the trachy-alaskitic intrusion; the second-period D veins a subsequent briefly sustained stage of temperature more normal to shallow depths; the third-period a relatively high but briefly sustained temperature following the alaskitic (Tonopah rhyolite) intrusion. No vein formation followed the andesite eruption.

The history of faulting is long and complex; important movements have taken place at every stage of the geologic history. These movements accompanied and were due to the volcanic disturbances.

Somewhat earlier, Burgess[1] reached a radically different conclusion from that formed by Spurr as to the nature of the several formations disclosed by the mining operations. He considered that the sequence shown by the formations is that in which they were formed — in other words, that the different formations originated as surface flows or accumulations of volcanic material—thus questioning Spurr's conclusion that many of these rock masses are intrusive. Burgess also notes that many of the productive veins continue downward into the West End rhyolite, and he implies, although he does not so state, that the mineralization in the two portions is contemporaneous.

The district has also been briefly discussed by Locke,[2] who in general agrees with Burgess that the formations are present in their proper stratigraphic sequence. Locke also questions the validity of Spurr's statement that the mineralization occurred at a number of epochs, and notes that "There is no mineralogical distinction whatever to be made between many veins which, according to the hypothesis [Spurr's] should belong to different periods."[3]

The most recent contribution to the geology of the district has been made by Bastin and Laney.[4] These authors confined their attention chiefly to a study of the ores, and did not concern themselves with either the stratigraphic sequence or the geologic structure of the district. With regard to the ores, however, they note that "Mineralogic differences between veins of supposed different ages are commonly no greater than may be observed in different parts of one continuous vein. * * * Upon the sole basis of the mineral composition and texture of the primary ore there would be little reason for the impartial geologic observer to regard the principal productive veins as of more than one age."[5]

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[1] Burgess, J. A., The geology of the producing part of the Tonopah mining district: Econ. Geology, vol. 4, pp. 681–712, 1909.

[2] Locke, Augustus, The geology of the Tonopah mining district: Am. Inst. Min. Eng. Trans., vol. 43, pp. 157–166, 1912.

[3] Idem, p. 164.

[4] Bastin, E. S., and Laney, F. B., The genesis of the ores at Tonopah, Nevada: U. S. Geol. Survey Prof. Paper 104, 1918.

[5] Idem, p. 9.

The results of the previous work may perhaps be very briefly summarized as follows: The district is underlain by a series of volcanic rocks, which are considered by Spurr to be in large part intrusive sills and by Burgess and Locke to be entirely of surficial accumulation. All these observers imply that these formations are relatively flat-lying and that their essentially horizontal continuity is disturbed only by faulting, the cause of which is attributed by Spurr to volcanic activity and is considered by Burgess to be in part a reflection of the irregularities in original distribution of the formations. Spurr postulates a number of different periods of ore formation, a view which is directly challenged by Locke, indirectly questioned by Burgess, and not supported by the work of Bastin and Laney.

Spurr, Burgess, and Locke all appear to agree in the fact that the "Midway andesite" is later than the period of ore formation and acts as a capping to the ore.

SUMMARY STATEMENT OF RESULTS OF PRESENT INVESTIGATION

During the 15 years or more that has intervened since the last work by Spurr, Burgess, and Locke there has been a considerable amount of development work done in the western half of the district, which has reached to much greater depths than in the older, central portion. This new work has disclosed a number of features of the geology that are not readily apparent elsewhere, and as a result, the writer's conception of the geologic setting at Tonopah is in part rather widely at variance with the views expressed by earlier writers. The points of difference may be divided into three groups—those relating to the stratigraphy, the structure, and the ore deposits.

The sequence of formations in the western part of the district is as follows: The oldest unit is that called by Burgess the "Lower rhyolite" and by Spurr, in his 1915 paper, the Tonopah rhyolite; for this unit the writer proposes the name Tonopah formation. It consists of interbedded rhyolitic flows, tuffs, breccias, and well-laminated silt composed largely of volcanic material, and is locally cut by dikes and small intrusive masses of similar composition. Interbedded with the Tonopah formation at two or more horizons are dark lavas, for the most part keratophyric, which are identical with rocks mapped by Spurr as the Sandgrass or "calcite" andesite. Similar rock exposed in the lower portions of Sand Grass and Extension No. 1 shafts may perhaps be an intrusive plug into the Tonopah formation. The next younger formation is the Mizpah trachyte, which might be termed more accurately a keratophyre. This formation probably overlies the Tonopah formation conformably, but in most places the contact between them has been a site for the intrusion of the irregular sill-like mass long known as the West End rhyolite. Earlier than the West End rhyolite but younger than the other formations is an intrusive mass of breccia, here named the Extension breccia, which appears to have been intruded along an old fault. Only two other formations, both of which appear younger than the ore, have been recognized in the underground work. The earlier is the Fraction breccia, elsewhere considered to be the basal part of the Esmeralda ("Siebert") formation. This, as well as the other formations, is cut by intrusive dikes of rhyolite porphyry, which are presumably similar to the Oddie rhyolite or Brougher dacite defined by Spurr. The writer was unable to distinguish the "Midway andesite," generally supposed to be later than the ore, in any of the underground exposures examined by him.

The extension of mining westward has brought to light a great deal of information concerning the geologic structure of the district. In this regard, particularly, some of the conclusions here reached must be considered as preliminary in nature and dependent for confirmation upon the detailed mapping of the eastern half of the district. In general, the formations have been tilted to form a westward-dipping monocline, the observed dips in which reach 60° or more in some localities. The dip on the whole decreases toward the east, and there is a suggestion, based upon observations in the deeper workings from the Midway and Mizpah shafts, that after passing through the horizontal it reverses, and the beds dip to the east. The tilted formations are cut by a remarkable compound fault, whose appearance in cross section is that of a recumbent crescent, convex upward. This fault may most conveniently be considered a transverse fault along which the rocks on the upper side have moved eastward for a total distance of about 1,500 feet. There are in addition a number of other faults, of considerable throw, that cut the crescent-shaped fault and represent several successive movements.

The occurrence of ore is intimately associated with the unusual fault mentioned in the preceding paragraph, in that almost all the ore bodies that have thus far been mined appear to be localized either in the fault itself, in faults that are hanging wall splits from its limbs, or in faults, many of them of almost insignificant throw, that roughly radiate from its crest. The factors that have governed this localization of ore shoots are probably several in number, and their relative importance is not known. The writer's present view is that at least three factors must have been operative during the formation of ore in any of the fractures above mentioned—(1) the fracture must have been situated above a certain isotherm (line of equal temperature) existing at the time of ore deposition; (2) it must have been open to the passage of solutions at that time; and (3) the wall rocks of the fracture must have been permeable to the solutions. Specific applications of these factors are discussed on a later page. The presence of quartz appears to have little or no bearing upon the localization of ore, and the writer believes that the bulk of the silver is of distinctly later introduction.

In addition to the ore deposits in fractures related to the major fault, ore has been found in three faults of later age. In each of these three, however, the strike of the productive part is close to the general strike of the other productive fissures—nearly east-west.

THE FORMATIONS

Tonopah formation—The name Tonopah formation is proposed for what has been previously called the "Lower rhyolite."[1] The formation has also been called the "Tonopah rhyolite" or "Tonopah rhyolite-dacite"[2] and correlated with rhyolite exposed on the surface north of the mining district. These exposures have not yet been studied by the writer, but from the descriptions of their lithology and relations they do not appear to be in any way related to the beds here discussed. The formation as here defined includes rocks that have been mapped previously as "Glassy trachyte" and "Montana breccia," but it does not include all the exposures that have been so assigned by Spurr, Burgess, and others.

The best exposures of the formation are found in the westerly workings of the Tonopah Extension mine, notably on the 1,200-foot, 1,540-foot, and 1,880-foot levels. Less extensive but equally significant exposures are present in the 1,050-foot level from the Extension No. 1 shaft, the 1,000-foot and 1,140-foot levels of the Sand Grass, the 700-foot level of the Mizpah, and the 800-foot and 960-foot levels of the West End. The formation may also be seen in many of the workings of all the other mines studied, but in these extensive alteration has generally served to mask its true nature.

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[1] Burgess, J. A., The geology of the producing part of the Tonopah mining district: Econ. Geology, vol. 4, p. 687, 1909.

[2] Spurr, J. E., Geology of the Tonopah mining district, Nevada: U. S. Geol. Survey Prof. Paper 42, p. 41, 1905; Ore deposition at Tonopah, Nevada: Econ. Geology, vol. 10, p. 745, 1915.

The outstanding feature of the formation is that it is composed of an interbedded sequence of volcanic breccias, massive tuffs of varying grain size, porphyritic flows, banded flows, and water-laid deposits of several kinds, the most striking of which is probably the well-laminated material that closely resembles much of the Esmeralda formation.

The rocks described by Burgess[1] as bedded pyroclastic material belong in this formation, and the exposures in the Tonopah Extension workings add abundant proof of the nonintrusive character of the great bulk of these rocks. Bedding planes are apparent in many places, and in numerous specimens there is an obvious gradation from coarse-grained material at the bottom of a bed to fine-grained material at the top. On one bedding surface well-developed ripple marks were noted. In addition, the fact that these rocks are interbedded with amygdaloidal flows of Sandgrass andesite renders it almost certain that the great bulk of the formation is a surface accumulation.

Some intrusive rocks are, however, included within the formation, as may well be expected in such an accumulation of dominantly volcanic débris. One of the clearest examples of such an intrusive is the strikingly porphyritic dike that is exposed on the 1,140-foot level of the Sand Grass, in the shaft crosscut, about 200 feet in the footwall of the vein. Other small intrusive dikes and masses of porphyry and breccia may be found at several localities. Those of breccia are probably related to the intrusive mass of Extension breccia, but it has not been practicable in all places to correlate them certainly with that body.

Strongly flow-banded rhyolites are interbedded with the other members of the formation in almost all exposures. This rock has been distinguished by some of the geologists who have visited the district as "Glassy trachyte." The writer, however, found it impossible to separate this rock satisfactorily because of its intimate interbedding in many places with tuff and breccia. Contortion of the flow banding is locally marked.

Mr. Ian Campbell has studied a number of specimens of this formation under the microscope and has submitted the following notes concerning them:

> In thin sections of the flow-banded rock phenocrysts are not common. Crystals of albite are found occasionally, and altered biotite more rarely. The matrix is everywhere much altered, either to quartz or sericite or both, and its original character is therefore uncertain. None of the rock in the sections studied is now glassy, although originally it

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[1] Burgess, J. A., op. cit., pp. 687–689.

may have been partly to wholly glassy in a few places. The writer believes that for the most part it was originally holocrystalline. The altered matrix consists of extremely fine to medium-grained feldspathic material, sericitized and in part silicified to greater or lesser extent. Flow structure is common, and in a few sections there is suggestion of a trachytic texture. Apatite and zircon occur as very scant accessories.

Quartz veinlets are the most striking feature of most sections. These appear to have been formed by replacement along the more permeable zones of the flow. Adularia occurs in these veinlets, but is by no means common. Sericite is generally present, especially along the middle of the veinlets. Another set of quartz veinlets, mostly mere threads, are found roughly at right angles to the main banding. These seem to follow cracks along which there has been a slight offsetting of the main bands. Pyritization of these rocks has been very common.

The clastic character of the breccias and tuffs is unmistakable in most thin sections. These rocks consist typically of angular fragments of quartz, orthoclase (both sanidine and adularia), albite, and very rarely microcline and microcline microperthite in a fine-grained groundmass which appears to consist mostly of feldspathic material. Quartz is much the most abundant of the larger fragments. Apatite (colorless) and zircon occur sparingly.

In some of the finer-grained tuffs the peculiar concave trilobate structure known as "eutaxitic texture" is well developed, indicating that the fragments were originally glass. They have since been altered to secondary quartz.

Alteration has affected these rocks in much the same heterogeneous fashion as it has the other formations of the district. Carbonatization and chloritization were perhaps the commonest types; but sericitization, silicification, and adularization have also occurred. Pyrite is widespread but not particularly abundant, and much of it is partly altered to siderite.

The bottom of the formation has not yet been exposed by the mining operations. In all but a few places its top is marked by the intrusive West End rhyolite, which separates it from the Mizpah trachyte. On the 1,330-foot level of the Midway mine, however, the intrusive is absent, and a normal contact between the Tonopah formation and the Mizpah trachyte is exposed. The beds are steeply tilted at this place, and the mine workings show that the two formations interfinger with each other, beds of tuff or breccia alternating with relatively thin layers of typical Mizpah trachyte.

As the base of the formation is nowhere exposed, its total thickness is not known. Approximately 1,000 feet is present in the western part of the Tonopah Extension mine, exclusive of the interbedded Sandgrass andesite.

The age of the formation is not definitely known. It is unconformable beneath the Esmeralda formation, of upper Miocene age, and contains fragments of black slate that presumably belong to the Cambrian or Ordovician, inasmuch as lithologically similar rocks in adjacent areas are known to be of lower Paleozoic age.[1] The greater portions of the Sandgrass andesite and Mizpah trachyte, both of which are of essentially the same geologic age as the Tonopah formation, are rich in albite and are similar to rocks at three other localities in Nevada that Knopf[2] has described as Keratophyres.[3] Almost all these rocks are of Mesozoic age but one occurrence at Cedar Mountain[4] is considered to be Tertiary. If similarity in composition may be used as a basis of correlation, the formation may be either of Mesozoic or Tertiary age. H. G. Ferguson has studied the Mesozoic rocks in the Tonopah and Hawthorne quadrangles and has also seen the exposures of the Tonopah formation underground, and he informs the writer[5] that the two are not at all similar in appearance. It would appear most probable, therefore, that the Tonopah formation is of Tertiary age (older than upper Miocene).

Sandgrass andesite—In Spurr's earliest examination of the district, rocks belonging to the Sandgrass andesite were considered to be an altered phase of the Mizpah trachyte and were called by him the "calcitic phase of the earlier andesite." When the formation was recognized as distinct from the Mizpah trachyte, the name was shortened by those working in the district to "calcite andesite."[6] In his final publication Spurr proposed the name Sandgrass andesite[7] for the formation, and this name is retained in the present report, although microscopic study has shown that the formation contains relatively little andesite, most of the rock being keratophyric.

The formation is exposed in all the mines that were examined during this survey, but its character and relations are best observed in the 960-foot level of the West End, the 1,540-foot and 1,880-foot levels of the Tonopah Extension, and the 1,000-foot and 1,140-foot levels of the Sand Grass.

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[1] Ferguson, H. G., Geology and ore deposits of the Manhattan district, Nevada: U. S. Geol. Survey Bull. 723, pp. 18–24, 1924. Ransome, F. L., Geology and ore deposits of Goldfield, Nevada: U. S. Geol. Survey Prof. Paper 66, p. 32, 1909.

[2] Knopf, Adolph, Geology and ore deposits of the Yerington district, Nevada: U. S. Geol. Survey Prof. Paper 114, pp. 13–16, 1918; Ore deposits of Cedar Mountain, Mineral County, Nevada: U. S. Geol. Survey Bull. 725, pp. 363–365, 368, 1921; Geology and ore deposits of the Rochester district, Nevada: U. S. Geol. Survey Bull. 762, pp. 20–23, 1924.

[3] The term keratophyre in recent years has been applied to essentially unaltered rocks which are similar to trachytes but which have a sodic plagioclase, albite or albite-oligoclase, in place of potash feldspar as the characteristic feldspathic mineral. This usage is retained in this report, although the word was originally applied to altered rocks in which the soda-rich feldspar was developed subsequently.

[4] Knopf, Adolph, op. cit. p. 368.

[5] Personal communication.

[6] Burgess, J. A., op. cit., p. 691.

[7] Spurr, J. E., Econ. Geology, vol. 10, p. 729, 1915.

Previous writers are not in agreement as to the true nature of this formation. Spurr considers it to be an intrusive sill-like mass, and Burgess implies that it is a flow, a view that is accepted by Locke. So far as the present examination went, the bulk of the formation as exposed underground is definitely extrusive. This is very clearly shown by the West End and Tonopah Extension occurrences cited in the preceding paragraph. At these localities the formation is composed of a series of flows of different composition and texture, some of which are strikingly amygdaloidal, and is divided into two separate bodies by an intervening strip of the Tonopah formation. The mass exposed in the workings from the Sand Grass shaft, however, is rather uniform in composition and texture and may be intrusive, though, on the other hand, the uniformity may be due to the fact that the workings that cut the formation are nearly parallel to the general strike, and thus expose only a single flow. The relation of this mass to the other formations is in large part masked by the presence of the intrusive Extension breccia.

In the Red Plume mine and in many of the workings from the old Midway shaft the Sandgrass andesite is also exposed. In these localities there is in general rather pronounced crushing and alteration, which has tended to mask the nature and relations of the formation. The boundaries of the formation in this region are somewhat irregular, but it appears most probable that this is due to a combination of an interfingering contact and folding than to intrusion. The interfingering of the andesite with the Tonopah formation may be observed on a small scale on the 530-foot level of the Midway mine; and the fact that folding has affected these two formations is apparent from the dips of the Tonopah formation in the lower workings from both the Red Plume and old Midway shafts.

The formation is dominantly gray-green to dark green, although locally, bands of nearly black basalt are interlaid with it. The bulk of the rock is porphyritic, but in both the basalt and the amygdaloidal portions this feature is not readily apparent. There are also some probable flow breccias in the formation where it is exposed in the Mizpah-Silver Top workings and in the West End mine near its boundary with the Jim Butler workings, but in all these localities the rock is rather thoroughly altered, and the nature of the supposed breccias is obscure.

Mr. Campbell has provided the following notes upon the microscopic features of the formation:

> In the amygdaloidal facies of the formation altered feldspars appear in a groundmass of chlorite. The feldspar phenocrysts are of small to medium size and, though mostly altered to calcite, appear to have been albite originally. Ferromagnesian phenocrysts were evidently rather rare. The amygdules show concentric filling by chlorite, calcite, and quartz. Pyrite is found as swarms of small cubes, but is only rarely present in the amygdules.
>
> The basaltic rock consists of about 30 per cent of small tabular fresh crystals of calcic andesine in a typical basaltic texture. The groundmass material is made up of exceedingly small lathlike feldspars, the interstices between which are filled with a fine-grained aggregate of chlorite and calcite. Magnetite in small subhedral grains is abundant, but apatite is relatively rare. Pyrite and zircon are absent.
>
> Specimens from the vicinity of the Sand Grass shaft show a seriate porphyritic texture of altered feldspar phenocrysts in a rather fine-grained, altered groundmass. The feldspars are almost completely altered to epidote, zoisite, sericite, chlorite, and calcite, but a few remnants indicate that their composition is that of albite. Other phenocrysts are also abundant and their outlines suggest that they were originally hornblende and very probably biotite. These are now completely altered to elongate prismatic forms outlined with a heavy "fuzzy" border of black iron oxides, the inner portion of which consists of chlorite and quartz, with locally a little carbonate or sericite. The groundmass seems to have suffered less alteration than the phenocrysts. Outlines of small lathlike to tabular feldspars in subparallel arrangement can be distinguished. These seem to be albite chiefly; though there may be a little orthoclase and quartz. Among them can be found all the alteration products mentioned above, with chlorite and calcite the most abundant. Apatite is fairly common throughout the rock, and all of it is the ordinary colorless variety. Zircon was not noted. Pyrite occurs sparingly in rather irregular aggregates.

The total thickness of the formation is not definitely known. On the 1,540-foot level of the Tonopah Extension approximately 500 feet are exposed, and a portion of a somewhat lower belt is present but its lower limit is concealed by faulting. The formation must be of the same age as the Tonopah formation, with which it is interbedded.

Mizpah trachyte—The rock of andesitic appearance first described by Spurr[1] under the name "Earlier andesite," as originally defined, also included the Sandgrass andesite, and therefore, in 1915, he renamed the formation the Mizpah trachyte.[2] This name is retained in the present report, although microscopic work has shown that albite is the only feldspar present, and the rock is in reality a keratophyre or albite trachyte, a distinction first made by Winchell in an unpublished report to the Tonopah Extension Mining Co. On the lower levels of the Tonopah Extension mine this formation has been called the Victor andesite.

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[1] Spurr, J. E., U. S. Geol. Survey Prof. Paper 42, p. 31, 1905.

[2] Spurr, J. E., Econ. Geology, vol. 10, p. 720, 1915.

In several of the mine workings there are exposures of the rock that have been mapped by other geologists as "Midway andesite" or "later andesite,"[1] and described by them as lying unconformably above the Mizpah trachyte and forming a "caprock" to the veins. So far as the writer's observations in the mines of the western part of the district show, the rocks assigned to the "Midway andesite" cannot be separated from the Mizpah trachyte by reason of any original differences in composition or texture, nor has he seen any examples of this rock capping any of the veins, or found in the literature reference to any specific example of it. In many places, it is true, extensive chloritization has affected these rocks and changed their appearance, but within such altered bodies less altered facies are found to be of the same keratophyric nature as the unquestionable Mizpah trachyte.

The least altered rock of the formation is normally a porphyritic rock of grayish-green or brownish-green aspect. The phenocrysts of feldspar are almost invariably somewhat dulled by partial alteration, are somewhat variable in size and number, and are set in a dense matrix locally flecked with chlorite. Pyritization has been rather widespread. Two other types of rock are found in the formation in a number of places. One of these is a flow-banded rock which is particularly abundant in the Wandering Boy workings, and is recognized less commonly in the other mines. The other is a fragmental rock, commonly a breccia, but locally tuffaceous, which is generally well-bedded. This variety was recognized in several places, particularly in the region between the Red Plume and new Midway shafts and in the Jim Butler and West End workings in the hanging wall of the West End vein.

Mr. Campbell writes:

> In thin section the Mizpah trachyte shows rather numerous and prominent albite phenocrysts, set in a fine-grained, somewhat orthophyric groundmass composed principally of albite and orthoclase. A little quartz in the groundmass may be primary, but it is difficult to distinguish from secondary quartz. In the interstices of the feldspars in the groundmass are scattered small shreds of chlorite and sericite. Ferromagnesian phenocrysts are very rare. Biotite may be inferred from its pseudomorphs, which are generally either sericite or

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[1] Spurr, J. E., U. S. Geol. Survey Prof. Paper 42, p. 33, 1915; Econ. Geology, vol. 10, p. 743, 1915. Burgess, J. A., Econ. Geology, vol. 4, p. 703, 1909.

chlorite. Apatite, much of which is pleochroic, is relatively abundant, and zircon rather scant. Magnetite or ilmenite may have been sparingly present, but if so, it is now entirely altered to rutile.

Albite, as noted above, is the chief feldspar. Its average composition is $Ab_{95}An_5$. The phenocrysts are tabular and usually show the typical polysynthetic twinning, except where this has been obscured by alteration. Neither pericline nor carlsbad twinning is particularly common. Zonal growths are almost unknown. All these phenocrysts are altered to a greater or lesser extent. Sericitization of the albite phenocrysts was the most widespread type of alteration. Locally, adularization occurred and there has also been replacement by quartz, calcite, and chlorite. Any two or even three alteration products may be found on a single crystal. Alteration of the groundmass is more difficult to estimate with accuracy. It seems to have proceeded more rapidly than that of the phenocrysts, but along the same general lines except that much altered specimens are found in which the phenocrysts have gone entirely to sericite, but the groundmass has become a mass of intergrown quartz and sericite, with quartz the more abundant. Even in specimens that appear to be but little altered it is common to find veinlets and nests of quartz or quartz and adularia.

A thickness of at least 2,000 feet of the Mizpah trachyte is indicated by the hanging-wall exposures in the Sand Grass and Tonopah Extension mines. The top of the formation is not known, except where it is unconformably overlain by the Fraction breccia. The Mizpah trachyte conformably overlies the Tonopah formation and must therefore be slightly younger.

Extension breccia—The name Extension breccia has been locally used in the district for an intrusive mass of breccia whose relations are best exposed in the Tonopah Extension mine; and as it is desirable to distinguish this mass, the name is retained here. It is probable that in some of the previous geologic mapping this formation has been included either with the Tonopah formation or with the "Montana breccia."

On the lower levels of the Tonopah Extension mine the breccia is found in the footwall of the Murray and Merger veins. The exposure continues up to the 600-foot level, but the area of breccia present on each level steadily decreases upward, because of the fact that the dip of the breccia mass is somewhat steeper than that of the vein. The Extension breccia is also found on the hanging wall of the combined Murray and Merger veins in the lower levels of the Sand Grass and Merger mines, but is by no means adequately outlined there because of the relative scarcity of mine workings.

The intrusive nature of the mass is clearly shown in only a few places, such as the 1,880-foot, 1,760-foot, 1,680-foot, and 950-foot levels of the Tonopah Extension and the 1,000-foot level of the Sand Grass, the relations in other localities being more or less masked by alteration near the veins. The intrusion appears to have been localized along an earlier fault, striking nearly east and dipping north, within the Tonopah formation. On the 1,140-foot level of the Sand Grass, for example, east of the main body of the intrusive, a narrow dike of the breccia is found in this fault zone, which here separates breccias and tuffs of the Tonopah formation from Sandgrass andesite. Still farther east on the 1,050-foot level from the Extension No. 1 shaft, however, the formation is absent from the fault zone. The actual contact of the intrusion is in many places difficult to locate exactly. Rock typical of the breccia passes gradually through a variety in which fragments of the invaded rock predominate, then to one in which they are exclusively present, and finally to shattered wall rock cemented by thin veinlets of the Extension breccia matrix.

The greater part of the intrusion is remarkably homogeneous in appearance, consisting of fragments of various rock types set in a characteristically reddish matrix containing rounded dark phenocrysts of quartz. The rock fragments included are largely of the Tonopah formation and less abundantly of the Sandgrass andesite and Mizpah trachyte. Not uncommonly small fragments of black shale are also found. Locally it is difficult to distinguish the formation from the breccias of the Tonopah formation, for in the vicinity of veins alteration has masked its relations and obliterated its distinctive characters.

Mr. Campbell's observations on the thin sections of this formation are as follows:

> Under the microscope most of the inclusions are banded rocks, trachytic rocks, eutaxitic-textured rocks, and tuffaceous rocks, and can be recognized as belonging to the Tonopah formation. The matrix is not usually easy to separate from the rest of the rock. It seems to consist almost entirely of fine-grained quartz, much of which is probably secondary. Large quartz grains are embedded in this matrix and are much corroded and resorbed. Throughout the matrix there is distributed a faint reddish-brown dust, undoubtedly an iron oxide, which must account for the red color observed in hand specimen.
>
> The Extension breccia shows the same kinds of alteration, with sericitization and silicification predominating, that the other formations have.

The maximum strike length of the Extension breccia mass was observed on the 1,880-foot level of the Tonopah Extension mine, where it amounted to nearly 1,500 feet. The maximum thickness (at right angles to the strike length) is not known because of the interruptions to the mass by faulting, but it is probably in the neighborhood of 1,000 feet.

The formation is later than the Mizpah trachyte, for it includes fragments of that rock, but it is older than the West End rhyolite, which intrudes it. It was probably formed in the same general period of volcanic activity as the Tonopah formation and its associated flows.

West End rhyolite—At the time of Spurr's earlier report the West End formation had been exposed in only a few shafts and was considered to be a part of what is called in this report the Tonopah formation. More extensive exposures, however, proved it to be a distinct rock, and it became known as the "Upper rhyolite," being described by Burgess[1] under that name, although he appears to have included in it rocks that have since been assigned to the Tonopah formation. The formation was redefined in 1915 by Spurr and named the West End rhyolite,[2] a name that is retained here.

Burgess describes the mass as being a series of flows, in contrast to Spurr's contention that it is an intrusive sill-like body, but the newer mine workings have exposed abundant evidence showing that Spurr's view is correct. Burgess's interpretation was in part due to the fact that he included in the West End rhyolite rocks that are now known to belong to the Tonopah formation.

The formation is best exposed in the Tonopah Extension and West End mines, where it is found as a westward-dipping mass separating the Tonopah formation and the Mizpah trachyte. By reason of faulting, this same mass is also found in the more easterly mines, where, however, its thickness is considerably less. On the 1,330-foot level of the Midway it is entirely absent, and a normal contact between the Mizpah trachyte and the Tonopah formation is exposed. After allowing for the extensive subsequent faulting it appears that the intrusive originally decreased in thickness northward and upward. A second smaller mass of the West End rhyolite is exposed in the extreme westerly workings of the district, a short distance in the footwall of the main body.

The intrusive nature of the formation is shown by several features. Perhaps the most convincing is the fact that it cuts through the Extension breccia, which is itself intrusive. At several places in the Tonopah Extension and West End mines the formation sends apophyses into the stratigraphically overlying Mizpah trachyte, and in some localities inclusions of that rock may be found within the rhyolite. The largest of these is the long, narrow wedge in the footwall of the West End vein on the 500-foot level of the West End mine. In addition to these larger features, the details to be observed at individual contacts exposed in the mine workings can be explained only by considering that the West End rhyolite is an intrusive mass.

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[1] Burgess, J. A., Econ. Geology, vol. 4, p. 692, 1909.
[2] Spurr, J. E., Econ. Geology, vol. 10, p. 737, 1915.

The rock most characteristic of the formation has a dense greenish matrix in which are set abundant angular fragments of white chalky rock. The number and size of the fragments vary greatly. Normally they form about a third of the rock and have an average diameter between a quarter and half an inch. Locally, particularly toward the east, they are tiny and in places almost completely lacking. Near contacts, on the other hand, the rock in many places is a coarse breccia, with inclusions as much as a foot in diameter, representing rocks of all the older formations, particularly those of the Tonopah formation. In the MacNamara mine, on the 400-foot level, similar coarse breccias may also be observed as bands within the formation. Wherever these variations in the number and size of inclusions are found in contact, it was observed that there is no sharp contact between the two phases, but rather a gradual blending over a distance of several feet. At the contacts of the formation the matrix shows chilling phenomena and is darker in color and glassy in appearance. A faint flow banding may be observed in several places, not only near contacts but within the mass of the formation.

Mr. Campbell writes as follows concerning the microscopic features of the formation:

> In thin section the rock is seen to be a very fine-grained but generally holocrystalline rhyolite. Sparse phenocrysts of quartz, albite, and orthoclase are found in a matrix of feldspar (probably orthoclase) and quartz (much of which may be secondary).
>
> The white inclusions so prominent in hand specimens are distinguishable with difficulty under the microscope. The "Glassy trachyte" and associated rocks appear to have furnished the material for the inclusions, because textures seen in a few of the sections are entirely similar to those characteristic of parts of the Tonopah formation.
>
> The alteration of the rock was chiefly sericitization, with an indeterminable amount of silicification. Pyrite is widespread and abundant in this formation, and many of the pyrite cubes are bordered by quartz or sericite. Quartz veinlets in the rock are of widespread occurrence, and in many of these adularia is a rather abundant accessory. Sericite occurs in such veinlets more rarely.

The maximum thickness of the formation appears to be exposed in the West End Extension and Tonopah 76 workings, where the main intrusion appears to be at least 600 feet thick. On the

1,330-foot level of the Midway, however, this has decreased to the vanishing point.

The West End rhyolite intrudes all the formations previously described but is, like them, unconformably overlain by the Fraction breccia.

Fraction breccia—For the formation which was first described by Spurr[1] as the Fraction dacite breccia and whose southern continuation in the Divide district was renamed by Knopf[2] the Fraction rhyolite breccia, the writer proposes the simplified name Fraction breccia, because at Tonopah the basal portion of the formation contains locally very large amounts of andesitic-appearing débris, with the result that there has at times been considerable confusion as to the proper correlation of the beds. They have, for example, been considered to represent the "Midway andesite"; indeed, all examples of "Midway andesite" cappings of veins that were seen by the writer proved to be this basal portion of the Fraction breccia.

The formation is exposed in the workings of the Jim Butler, MacNamara, West End, West End Extension, Monarch Pittsburg, and Tonopah 76 mines as a generally southward-dipping mass that unconformably overlies the older formations and the veins. In detail the lower contact of the beds is very irregular, showing that the surface upon which they were deposited had moderate relief. In many places the major faults that affect the veins appear to have exerted a control upon this old surface, for the breccia extends deeper where such faults formerly reached the surface. In addition, relatively slight renewed movement along many of the faults has resulted in shearing of the breccia.

The formation as exposed underground is almost everywhere a massive rock without any indication of bedding, although in a few places interlaminated fine-grained material may be observed. Near its contact with the older rocks it is generally sheared, presumably as a result of the later earth movements that imposed upon the formation its general southward dip. The basal beds are commonly made up almost exclusively of rock fragments that are andesitic in appearance, although most of them are undoubtedly keratophyres derived from the Mizpah trachyte. The proportion of matrix in this variety is in many places relatively small, and for the most part the matrix has the same dark color as the fragments. Higher up in the formation the rock is lighter colored and has a lower ratio of fragments to matrix. Of this portion Mr. Campbell writes:

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[1] Spurr, J. E., U. S. Geol. Survey Prof. Paper 42, p. 39. 1905.

[2] Knopf, Adolph, The Divide silver district, Nevada: U. S. Geol. Survey Bull. 715, pp. 150–154, 1921.

> The matrix is light colored, exceedingly fine-grained, and under the microscope appears holocrystalline to hypocrystalline. Fluidal texture has been observed. The aggregate index is lower than Canada balsam and higher than gamma of sanidine. Phenocrysts of quartz and sanidine are abundant, and there are a few of albite and biotite. The sanidine is generally much altered to calcite, the albite somewhat altered to sericite, the biotite also to sericite. There has been some silicification throughout the rock and heavy kaolinization locally. Pyrite, partly altered to limonite, occurs sparingly.

Only a small part of the formation is exposed in the underground workings so far examined, and the determination of the total thickness must wait until the surface exposures have been adequately studied.

The Fraction breccia is considered by Ferguson to be the basal member of the Esmeralda ("Siebert") formation[1] and is therefore of upper Miocene age.

Rhyolite dikes—Dikes of rhyolite were observed in two of the mines examined. On the 1,680-foot, 1,760-foot, and 1,880-foot levels of the Tonopah Extension mine in the vicinity of the Cash Boy shaft, there is a thin dike which in one place at least cuts cleanly across the veins. Larger masses of similar lithology are exposed on the 800-foot level of the West End and West End Extension mines, cutting both the Fraction breccia and the older formations.

In both occurrences the rock is a light-colored, rather fine-grained rock with abundant quartz phenocrysts. Mr. Campbell has examined these rocks under the microscope and reports as follows:

> In thin section the quartz phenocrysts stand out prominently. They are generally rounded but locally are embayed as a result of resorption, are slightly fractured, and are rather free from inclusions. Phenocrysts of sanidine are common, and in one specimen these show partial alteration to calcite. More rarely albite occurs. An occasional small flake of biotite, now altered to sericite, was noted. The groundmass has been much silicified, as is well shown in one specimen where the secondary silicification has produced "enlargements" of quartz phenocrysts, similar to the well-known quartz enlargements that occur typically in quartzites. If we discount this alteration it seems likely that this groundmass was holocrystalline and composed of quartz and orthoclase. There has been in places a slight sericitization, and locally small patches of calcite occur. Some pyrite was also noted.

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[1] Ferguson, H. G., Geology and ore deposits of the Manhattan district, Nevada: U. S. Geol. Survey Bull. 723, pp. 42–43, 1924.

No attempt has been made to correlate these rocks with the several types of rhyolite and rhyolite-dacite described by Spurr from surface exposures.

FOLDING AND FAULTING

Previous publications on the Tonopah district have described the several formations as being essentially horizontal[1] and have implied that the bulk of the major faulting was later than the deposition of ore.[2] The more extensive exposures available during the present examination indicate that these earlier conclusions are in error, for the formations are considerably tilted, and faulting appears to have been far more pronounced before mineralization than afterward. The apparent horizontal attitude of the formations in the older central portion of the district is in large part the result of premineral faults.

The block diagram included as Plate I of this report (in pocket) presents all the principal structural features of the western part of the district. This method of illustration was chosen because in no other way could the relations between dominantly eastward-striking veins and northward-striking formations be adequately shown. There are, of course, some objections to the method, one of the most important being that all the mine workings cannot be shown, but it is thought that these are outweighed by the numerous advantages. For several areas where there are no mine workings the writer has projected geologic features seen in surrounding areas. In a district where faulting is so widespread this is rather a dangerous procedure, and the doubt that is attached to such projections is indicated by question marks.

Many of the formations as already noted show either flow banding or sedimentary bedding planes, and these features are sufficiently abundant to provide adequate information as to the attitude of the rocks in most of the workings examined and to permit correlation of unfaulted contacts from level to level. They show that in the western part of the district there is a regional westward dip that averages close to 45°. The dips appear to decrease toward the east, and on the 700-foot and 800-foot levels of the Red Plume mine low northerly and easterly dips may be observed. On the 700-foot level of the Mizpah mine low easterly dips predominate, thus indicating that the beds are folded into a northward-plunging anticline. On the 630-foot level of the Midway mine in the vicinity of the old shaft there is apparently a moderate amount of minor folding on or near the crest of the anticline, to judge from the divergent dips observed there and also from the irregularity of the contact between the Tonopah formation and the Sandgrass andesite.

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[1] Burgess, J. A., Econ. Geology, vol. 4, fig. 87, p. 705, 1909. Locke, Augustus, Am. Inst. Min. Eng. Trans., vol. 43, pp. 157, 159, 1913. Spurr, J. E., Econ. Geology, vol. 10, p. 713, 1915.

[2] Spurr, J. E., op. cit., pp. 766–769. Burgess, J. A., op. cit., pp. 709–711.

Faulting appears to have been much more effective in the premineral deformation of the district than folding. It clearly occurred at several stages, to judge from the relations of the faults to one another, but practically all of the faulting must have occurred during the interval between the intrusion of the West End rhyolite and the deposition of the Fraction breccia. The only earlier fault that could be distinguished is the nearly east-west fault that localized the intrusive mass of Extension breccia.

The first major fault formed after the intrusion of the West End rhyolite was a unique compound fault, here termed the Tonopah fault, whose appearance in cross section approaches that of a recumbent crescent, convex upward, and whose crest trends nearly east and plunges to the east. (See fig. 1.) The fault is economically the most important single structural feature in the district, for it not only has played a dominant part in determining the present distribution of the formations but has been the chief factor in the localization of the ore bodies, in that, together with its subsidiary fractures, it has provided the courses along which mineralization took place. Ore bodies along different parts of the fault have received different names, some of which are shown on the figure.

Figure 1 shows the extent to which the fault has been exposed by mine workings—for considerably more than 1,400 feet vertically on its north limb and for nearly 700 feet vertically on its south limb. The junction of the lower branch with the upper branch on the north is well exposed on the 500-foot level of the Tonopah Extension mine. This locality is not shown on Plate I. The diagram, however, does show the junction in cross section between the 600-foot and 660-foot levels of the Tonopah Extension mine, about 500 feet southwest of the Sand Grass shaft. The upper branch is apparently unmineralized at this point. The comparable junction to the south has not yet been found, but the dips of the two branches indicate that it very probably exists. The crests of these two "anticlinal" branches both plunge to the east at low angles, ranging from 5° to 20°. The present rather inadequate exposures of the crest of the lower branch suggests that it plunges at a lower angle than the upper.

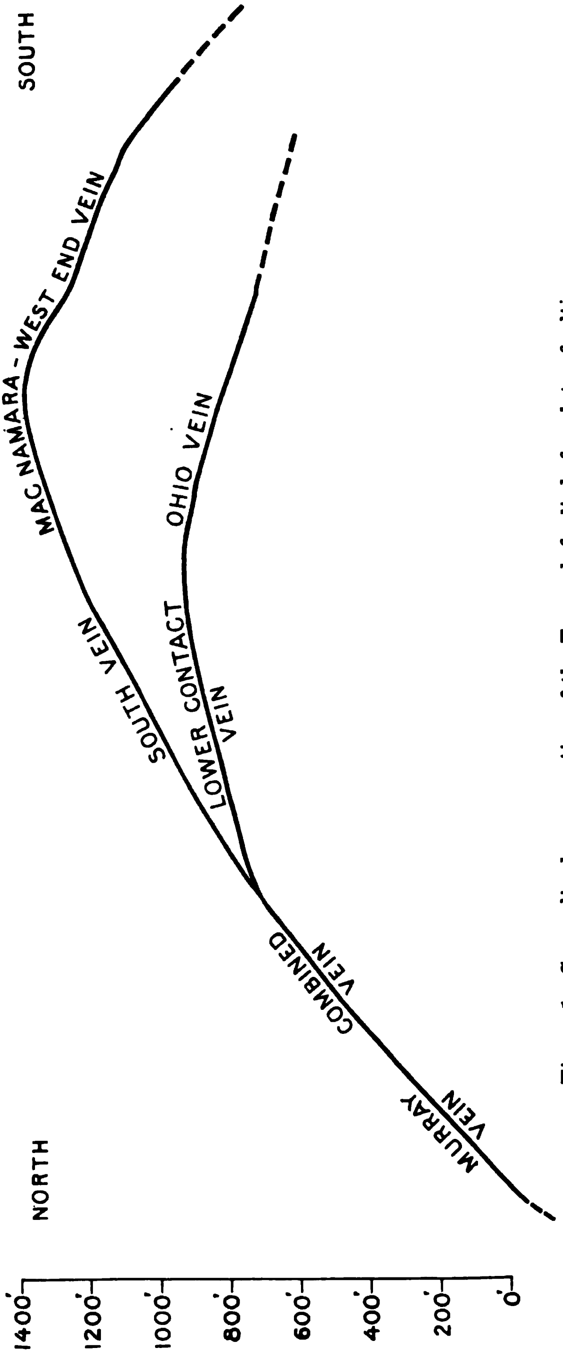

Figure 1—Generalized cross section of the Tonopah fault, before later faulting.

The appearance of the cross section of the fault suggests at once that it is simply a folded fault that originally had a uniform dip. This view is not tenable, however, because there is no similar folding in the formations adjacent to the fault—in fact, as noted above, the axis of the major folding in the wall rocks is at right angles to the axis of the crest of the fault. The throw along the fault may best be measured by the displacement of the nearly northward-trending contacts between formations on both sides of the essentially eastward-trending fault, as is well shown by the contact between the West End rhyolite and Mizpah trachyte on the 1,540-foot level of the Tonopah Extension mine.

The determination of the displacement along the fault, however, is somewhat complicated on the upper levels because of the presence there of a number of subsidiary, related faults that branch from its flanks and radiate from its crest, and because the dip of many of the contacts between formations there decreases rapidly eastward as the axis of the anticlinal fold is approached. On the lower levels the total horizontal shift of an individual contact by the fault and its splits is about 1,500 feet. Less trustworthy information on the upper levels also gives a figure close to this, but here the displacement is divided almost equally between the two major branches that form the crest of the fault.

The subsidiary related faults are most abundant on the upper levels. The only large one found at depth on the north limb of the main fault is mineralized and is locally known as the Merger vein. Its line of junction with the main fault plunges steeply to the east, and the two diverge from each other to the west. West of the point of junction the displacement along the main fault decreases by about one-half, the remainder being along the branch fault. No comparable branch or split has yet been observed along the south limb of the Tonopah fault.

The radiating faults along the crest of the fault differ from those on the flanks in that their lines of intersection with the main fault are nearly horizontal and their divergence is in a vertical rather than a lateral horizontal direction. Several of these fractures have been developed in the property of the Tonopah Mining Co., although most of them have only a very slight throw. The principal one is that occupied by the Mizpah vein and by its probable extension to the west as the Red Plume-Extension North vein. The latter has a maximum vertical displacement of several hundred feet, which, however, as in almost all the others of these faults that are sufficiently well developed, decreases rapidly, both upward and westward. This feature is particularly well shown along the Mizpah vein in the workings from the Mizpah shaft, the Extension North vein in the Extension mine, and the Egyptian vein in the Extension and West End mines. As the throw decreases the fracture generally steepens in dip, and in many places splits into two or more branches. This is particularly well exhibited along the Valley View vein and Mizpah vein.

The method by which the Tonopah fault was formed is not clearly understood. It must have developed in essentially its present form, for the wall rocks fail to show any comparable deformation, and hence it is obvious that the movement along it was essentially horizontal. It also appears probable that its origin is closely connected with that of the northward-trending anticlinal fold, although the anticline is clearly earlier, its axial plane being also offset by the fault. However, it is not known whether the fault was formed as a result of differential pressure continuing after the folding and is therefore in the nature of a transverse fault or flaw, or whether it represents a slump, following too great a piling up of volcanic material near the surface as a result of the folding, or whether it was formed in some other way. The apparent absence of drag effects near the fault perhaps favors the second view.

There are, in the western part of the district, some other premineral faults of sufficiently great economic importance to warrant special mention in this preliminary report. These may be assigned to four groups of different ages, each group characterized by certain strikes and dips. There are many other faults that displace the veins, but they have not caused any confusion in mining operations.

The oldest group of faults that cut the Tonopah fault trend northwest to west-northwest and dip at a moderately low angle to the northeast. Two faults have been placed in this group, both with rather large throws. The more westerly has been considerably developed in West End Extension and Tonopah 76 ground and in the Tonopah Extension, as it has been mineralized and contains an ore shoot that is known in the Extension mine as the Merton vein. The horizontal shift of the contact between West End rhyolite and Mizpah trachyte along this fault amounts to more than 1,000 feet on the 1,540-foot level of the Tonopah Extension mine, and as the contact dips about 45° in that place, the vertical movement along the fault must have been the same. In the workings along this vein on the 1,540-foot level, southwest of the McKane shaft, it is clear that the fault is compound, in that there are two major branches, which in places must be

200 feet apart. To the west, however, they appear to join. The workings on the 800-foot level of the West End Extension and Tonopah 76 mines do not show a similar branching, unless the two masses of quartz found in the workings south of the main crosscut, or "Long Shot," represent the western junction of the branches.

The second of the two faults in this group may be called the Monarch-Pittsburg fault, as it has been rather extensively explored in the mine of that name, where it appears to have been mineralized. It has also been exposed on the 800-foot and 960-foot levels of the West End mine, where it cuts off the Ohio vein, and in the lower levels of the Tonopah Extension mine, where it offsets the Murray vein. The fault is essentially continuous between the exposures in the Extension and those in the Monarch-Pittsburg, but is cut and displaced by two large younger faults in the region between the Monarch-Pittsburg and the West End. The offset of the Murray vein in the Tonopah Extension mine indicates that the vertical movement along this fault must amount to about 1,000 feet. The Monarch-Pittsburg fault, like the parallel fault to the west, is compound, two major branches, which unite both to the southeast and to the northwest, being observed in the more westerly workings. In the Tonopah Extension mine this fault is known as the Denver fault.

Only one fault was recognized that may be placed in the second group. This fault, which is known in the Extension mine as the Rainbow fault, has a northerly to northeasterly strike and an easterly dip. It is best exposed on the 600-foot level, about midway between the Extension No. 1 and Sand Grass shafts. In most of these exposures the strike is nearly north, but southward toward the 600-foot level of the McNamara mine the fault splits, and the main branch assumes a northeasterly strike. The workings on the Ohio vein, particularly on the 555-foot level, show that this southeasterly branch is cut and offset by the Extension fault of the third group. The vertical movement along the fault is about 150 feet in the lower levels of the mine. On the upper levels the throw decreases and is divided between several branches; the movement along the main southwesterly branch was about 50 feet.

The third group of faults has a northerly strike and a steep westward dip. The throw along them is relatively small compared to that along the faults of the first group. The most thoroughly developed fault in the group is the Extension fault, which has been exposed throughout the vertical range of the

Tonopah Extension workings and is also shown in parts of the MacNamara and West End mines. On the lower levels of the Extension mine the vertical movement along the fault amounted to about 125 feet, but on the upper levels it appears to have been somewhat less, in part at least because of the development upward of several branches.

The most westerly fault of this group is the 76 fault, exposed both in the Extension and in the West End Extension and Tonopah 76 mines, where it offsets the Merton vein. The vertical throw is somewhat less than 100 feet. Another fault of this group is present near the McKane shaft, where it offsets the earlier Monarch-Pittsburg fault. It may be called the McKane fault. The vertical movement along it is about 150 feet just above the 1,540-foot level but appears to decrease rapidly upward, amounting to about 50 feet in the Monarch-Pittsburg workings. These workings were not accessible, and it is not clear if this decrease in throw is the result of branching upward, as in the Extension fault.

A somewhat different behavior is exhibited by the fault to the east. This fault, which is unnamed, is about halfway between the McKane and Extension faults and is exposed in the workings from the Extension No. 2 shaft and the Extension incline. The maximum displacement along the fault in this vicinity appears to have been about at the 1,260-foot level, where the Murray vein has been dropped on the hanging-wall side about 100 feet vertically. Below this level the fault passes into a flexure, as is shown by the curving hanging wall of the Murray vein on the 1,540-foot level. Above the 1,260-foot level the throw decreases, and on the 850-foot level is comparatively insignificant. This fault appears to be represented to the south by a fault of similar strike and dip that is exposed in two places on the 800-foot level from the Ohio shaft. Here, however, the throw is considerably greater, as the offsetting of the Monarch-Pittsburg fault by it indicates a vertical drop of at least 200 feet.

The last fault of the third group that need be considered here is one found in the western part of the property of the Tonopah Mining Co., which has been called the Buried fault. This fault cuts the nose of the upper branch of the Tonopah fault and drops it to the west slightly more than 100 feet. The workings from the Wandering Boy shaft indicate that it frays out southward and upward, and as it could not be recognized in the Midway workings it must also die out northward. It is not certain that this fault is of the same age as the other faults in this group, for it appears to offset minor faults of similar strike to those that have been placed in the fourth group.

The faults of the fourth group strike northeast to east-northeast and dip at different angles to the southeast. The most interesting fault of this group is one that has been called the MacNamara fault in the mine of that name. This fault is well exposed in the upper levels of the MacNamara and West End mines, where it displaces the upper branch of the Tonopah fault and may be correlated with a fair degree of certainty with a fault of similar strike and dip that cuts the Ohio vein on the 700-foot level of the MacNamara and 800-foot level of the West End. On the latter level the fault is clearly later than the Extension, Rainbow, and Monarch-Pittsburg faults. In this region the vertical displacement along the fault ranges from more than 200 feet on the western portion of the 800-foot level of the Ohio to less than 50 feet where it cuts the Tonopah fault on the 500-foot level of the Tonopah Mining Co. East of the latter point, however, the character of the fault appears to change completely near the hanging wall of the older Tonopah fault. The dip decreases notably, and the fault takes on a rolling habit which appears to be partly controlled by the low eastward pitch of the nose of the Tonopah fault. This is well exhibited on the most westerly workings of the 600-foot level from the Mizpah shaft and on the 530-foot level of the Midway. The displacement along this rolling portion of the fault is considerably greater than that shown by the offsetting of the Tonopah fault to the west. This feature appears to be most readily explained by considering that the excess movement along this portion of the MacNamara fault is represented elsewhere by renewed movement along the upper branch of the Tonopah fault, which roughly corresponds to it in strike and dip.

The fact that the MacNamara fault resumes its normal character upward away from the Tonopah fault is shown by the workings north of the shaft on the 500-foot level of the Red Plume mine.

Another major fault in this group is the Sand Grass fault, which is well exposed only on the 600-foot level of the Sand Grass mine, where it cuts the shaft, and on the 660-foot level of the Tonopah Extension mine. It is thought that exposures of faults with similar strike and dip on the 1,050-foot and 770-foot levels from the Extension No. 1 shaft and the 1,000-foot level of the Ohio represent the same fault; and others on the 600-foot level of the Monarch-Pittsburg and the 800-foot level of the West End Extension-Tonopah 76 just west of the Monarch-Pittsburg connection are still more western extensions. To the east the Tonopah fault is dropped more than 150 feet vertically by the Sand Grass fault, but on the 660-foot level of the Extension this displacement is distributed along several branches.

Several other faults of similar strike and dip are exposed in the properties of the Tonopah Mining Co., Jim Butler, and West End, but the throws along them are relatively small. One of the best known of these is the Silver Top fault, in the ground of the Tonopah Mining Co., which offsets the Valley View vein throughout the mine.

The movement along the faults of all these four groups must have been largely accomplished before the deposition of the ore, for essentially unshattered quartz has been deposited in places along almost all of them. In some of these occurrences such quartz is continuous with the quartz of the mineralized Tonopah fault and its related fault veins. In addition ore has been stoped from several of the faults, as on the Merton vein in the Tonopah Extension and West End Extension-Tonopah 76 and on the Rainbow fault in the MacNamara. There has of course been post-mineral movement along some of the faults, for in several places quartz pebbles are present in the fault gouge, but this movement appears to have been relatively slight.

THE ORE BODIES

The form and character of the silver-rich ore bodies have been thoroughly described by Spurr[1] and by Bastin and Laney.[2] The following quotations from the latter authors rather inadequately summarize some of their conclusions regarding the ores:

> As emphasized by Spurr, the ores of Tonopah are in the main replacement deposits along sheetlike zones of fracturing. They are therefore typical replacement veins. Every gradation may be traced from heavy sulphide ore into slightly replaced wall rock. Ore-cemented breccias, true crustification, comb structure, and other features characteristic of the filling of open spaces are rare or developed only on a small scale. Banding somewhat resembling true crustification, which is locally conspicuous, is possibly to be explained by diffusion during replacement. * * *
>
> Although supergene mineralization has played an interesting part in the genesis of certain of the Tonopah ores, it appears to have been quantitatively much less important than the hypogene mineralization.

---

[1] Spurr, J. E., U. S. Geol. Survey Prof. Paper 42, pp. 83–96, 115–207, 1905.

[2] Bastin, E. S., and Laney, F. B., U. S. Geol. Survey Prof. Paper 104, 1918.

Most of the ore bodies in which it was most prominent are worked out, and the principal dependence of the mines today is upon ores that, the writers believe, are almost wholly of hypogene origin.[1]

In view of the adequate description of the character of the ores given in these two publications, it seems desirable in this preliminary report to consider only the factors that are thought to have been active in the localization of the ore bodies. A complete discussion of this subject, however, is not possible, for it would require the use of physico-chemical data that are only partly known. The following paragraphs, in which the factors derived empirically from a study of the known ore bodies are considered, may nevertheless prove of some benefit in directing future exploration.

The most outstanding feature of the known ore bodies in the western part of the district is their localization in the Tonopah fault and its subsidiary fractures. There is, of course, no direct connection between the ore and the fault, because extensive faulting intervened between the formation of the Tonopah fault and the deposition of the ore, and the later faults are only locally mineralized. It would seem rather that at the time the silver mineralization occurred the nearly east-west Tonopah fault and its associated fractures were parallel to compressive forces existent at that time, and they therefore were capable of being open to the mineralizing solutions. Applying this conclusion to future exploration would suggest that, subject to the limitations imposed by the other factors, development work should be confined to the Tonopah fault and its branches and splits, almost all of which are found on the hanging wall, and to such other fractures or faults as have a parallel strike. The fractures that radiate from the crest of the upper branch of the main fault appear to have been rather thoroughly explored, but this cannot be said for those that radiate from the crest of the lower branch. One such fracture has been found to be ore bearing in the West End mine, and it is possible that other similar ones may be present.

Ore bodies are unfortunately not found everywhere along the Tonopah fault and its branches; and there obviously must be additional factors governing their local distribution. The writer believes that the most essential requisites for the deposition of ore along these fractures were, first, that they should be open to the flow of the ore solutions at the time the solutions were circulating, and second, that the wall rock along such open fractures should be of a nature to facilitate precipitation and accumulation of the silver minerals.

---

[1] Bastin, E. S., and Laney, F. B., op. cit., pp. 9–10.

The first of these two requisites at first may seem unnecessary, in that it was shown above that the Tonopah fault in all probability was the path along which the ore solutions circulated, because it was open. However, in many places along the Tonopah fault there are large masses of quartz in which the silver content is too low to be minable, and in other places, particularly in the hanging-wall branches of the Tonopah fault, there are veins containing ore of rather high grade in which quartz is relatively scarce. These two features suggest strongly that the silver mineralization was in large part independent of the introduction of the bulk of the quartz found in the veins. Examination of ore specimens confirms this belief, for it shows that the ore minerals and those associated with them are distinctly later than the quartz. It is therefore plain that in many places the Tonopah fault could have been effectually sealed to the passage of the mineralizing solutions by the introduction of essentially barren quartz, and that renewed, postquartz movement was essential to permit the formation of an ore body.

In several places along the fault, however, there are no quartz masses, and in others there are quartz bodies with well-defined walls. In both of these types of occurrence there should have been some ore deposition if freedom for the passage of solutions had been the only requirement. Both, however, are locally barren, and this most probably may be attributed to the fact that the wall rock at these places was of such a character that it formed relatively impermeable gougy material adjacent to the active fault. This condition contrasts with the conditions existing near ore shoots, where the rock is of such a nature that both it and the adjoining quartz were fractured to form a readily permeable breccia. With respect to this character, the rock may be most conveniently referred to as nonbrittle or brittle, the latter being the favorable type. The brittleness cannot be directly correlated with the different formations described, but is rather connected with the kind of alteration they have undergone. Thus, on the property of the Tonopah Mining Co., the Mizpah trachyte has been altered to a hard brittle white rock composed largely of quartz and adularia, and forms the wall rock of numerous valuable veins. Farther west, however, chloritic alteration has changed the formation to a relatively plastic or nonbrittle rock in many places, in which ore deposits are relatively scarce. Conversely the bulk of the West End rhyolite in the Tonopah Mining Co.'s ground is soft and unfavorable for ore deposition, but in the Tonopah Extension and West End mines extensive silicification has converted it into material that has afforded ample fractures for admission of the ore-depositing solutions.

The determination as to the direction of exploration based upon these two factors is a somewhat more difficult matter than that based upon the relation of ore to the Tonopah fault. It appears to the writer that the character of the wall rock is by far the more important of the two in relation to possible ore deposits, in that if this condition is satisfied along a known fracture it is probable that the fracture will be found to have been open to ore-bearing solutions at some place along its strike or dip. Prediction as to the character of the wall rock must necessarily be based upon the observed alteration. At present it is not possible to delimit areas in which favorable rock may be expected to occur, but from the work thus far accomplished it seems probable that this may be done when the field work has been completed.

The final factor—that of depth—demands recognition, but the data available are not sufficient to determine its true importance. The fact that some of the ore bodies decrease in value with depth has been noted by Bastin and Laney,[1] and in similar occurrences seen by the writer the decreased silver content does not appear to be explained by the action of any of the three factors above set forth. In such occurrences the appearance of the vein material is not greatly changed, except that the sulphides present are almost entirely those of the base metals, silver sulphides occurring only sparingly. It is impossible to set a definite elevation at which this decrease may be expected to be operative, for the few localities at which it is thought to have occurred vary considerably among themselves; for example, the inadequate information now available appears to show that this depth may be different on either side of a premineral fault. The writer believes that these features may best be explained by considering that the depth of ore deposition was also controlled by the temperature of the ore-depositing solutions, in that above a certain temperature the precipitation of silver sulphides was impeded; and that at different localities this temperature was reached by the cooling, ascending solutions at different elevations, because of differences in the facilities for movement of the solutions along the ore channels. In general, it seems to be true that the required elevation was higher in the central part of the district than it was in the western part, but this statement is subject to many local variations.

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[1] Bastin, E. S., and Laney, F. B., op. cit., p. 44.

CONCLUSIONS

The geologic relations that have been disclosed by the resurvey of the Tonopah district would appear to warrant continued exploration whenever economic conditions are favorable. The work has shown clearly that ore deposition occurred relatively late in the geologic history, and that, as a result, ore may be found in several geologic formations rather than being limited to one. If future exploration is based upon the several factors that appear to have controlled ore deposition, it seems probable that such exploration will be rewarded by new discoveries of ore.

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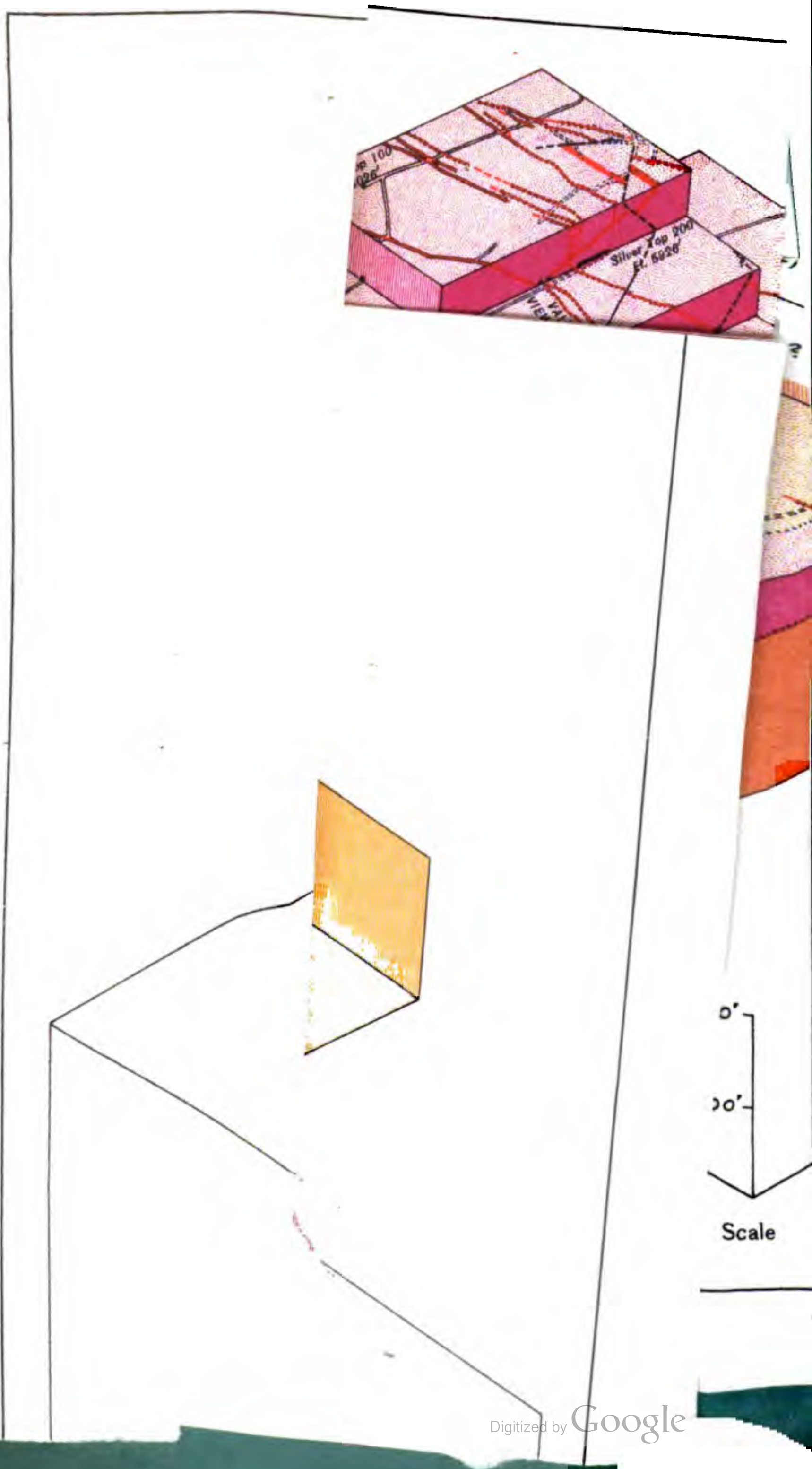
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BULLETIN OF NEVADA STATE BUREAU OF MINES AND MACKAY SCHOOL OF MINES

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BULLETIN OF NEVADA STATE BUREAU OF MINES AND
MACKAY SCHOOL OF MINES

NOTES ON ORE DEPOSITS AT CAVE VALLEY, PATTERSON DISTRICT, LINCOLN COUNTY, NEVADA

By F. C. SCHRADER
Geologist, U. S. Geological Survey

PREPARED AND PUBLISHED BY THE NEVADA STATE BUREAU OF MINES
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PUBLISHED QUARTERLY
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A Preliminary Survey of the Scossa Mining District, Pershing County, Nevada, 1931	**Gratis**
Notes on Ore Deposits at Cave Valley, Patterson District, Lincoln County, Nevada, 1931	**Gratis**

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ORE DEPOSITS AT CAVE VALLEY, PATTERSON DISTRICT, LINCOLN COUNTY, NEVADA[1]

By F. C. SCHRADER

INTRODUCTION

The visit to Cave Valley that formed the basis of this report was prompted in the summer of 1930 by a request from the Congressional Committee on Appropriations of the House of Representatives to the Geological Survey for an investigation of radium reserves. The deposits at Cave Valley had recently been reported to contain uranium, which is the source of radium, and the writer was therefore delegated to examine them; but the results of the examination were negative. Small shoots of silver-lead ore have been mined in this locality, and the outlook for the district depends principally upon conditions that would favor the working of similar ore bodies.

For courtesy and valuable information received, thanks are due to officials of the Great Western Mining & Development Co., especially Mr. Claude Morris, without whose aid in the field the illustrations and much of the material contained in the report would not have been available.

LOCATION

Cave or Steptoe Valley is in the Patterson (Geyser) district, about 50 miles south of Ely and 45 miles north of Pioche, which are the nearest railroad stations. It covers the south end of the Shell Creek Range, which here is high and narrow and separates Lake Valley on the east from Cave Valley on the west. Patterson Pass stands at an elevation of about 7,250 feet, and Patterson Peak, six miles north of the pass, at 10,000 feet, or 3,500 feet above the adjacent valleys. The principal supply point is Ely, which is reached by a good road along the long, narrow Cave Valley.

EARLY DEVELOPMENTS

The Patterson district has been described more fully by Hill[2] and more briefly by Lincoln,[3] according to whom the country rocks consist of Cambrian quartzite, limestone, and shale, which

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[1] Published by permission of the Director, U. S. Geological Survey.

[2] Hill, J. M., Notes on some mining districts in eastern Nevada; U. S. Geol. Survey Bull. 648, pp. 120–124, 1916.

[3] Lincoln, Mining districts and mineral resources of Nevada, pp. 123–124. Reno, 1923.

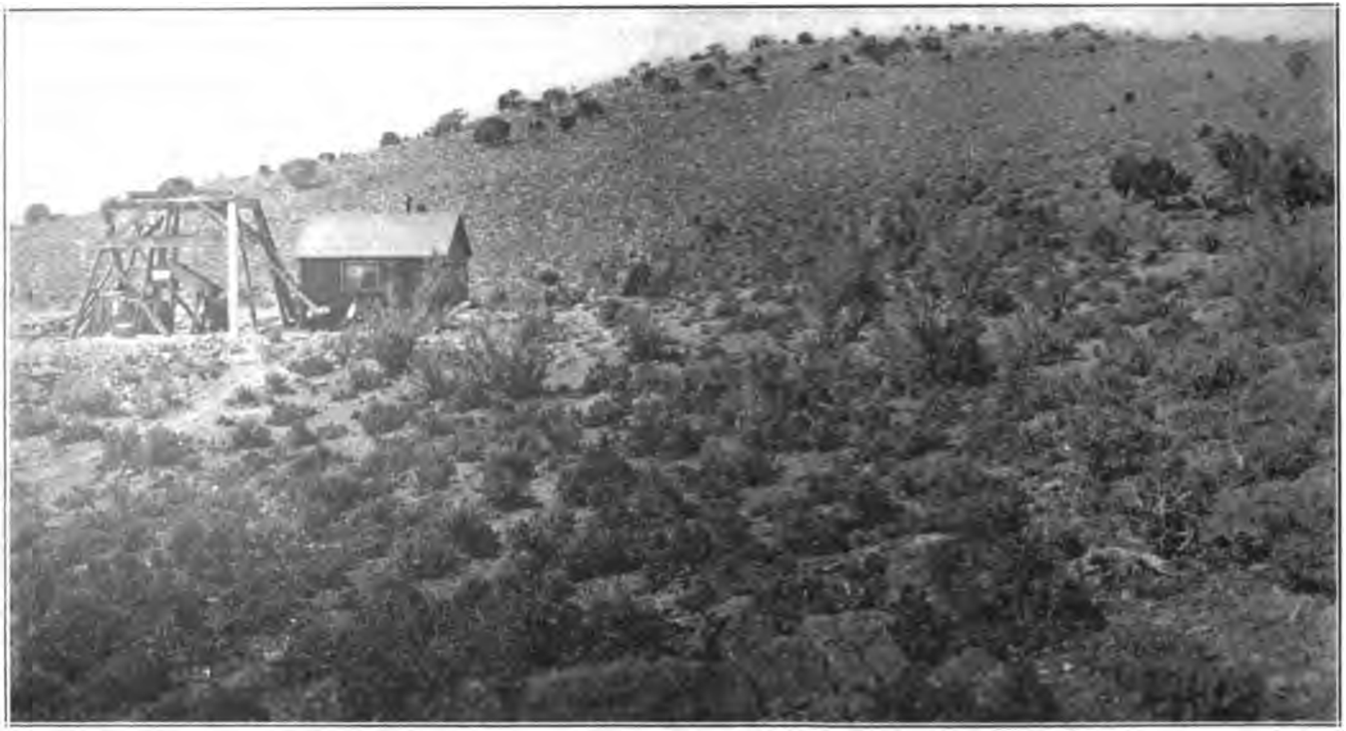

Fig. 1. Photograph showing Cave Valley Mine, Topography and Limestone Formation. Looking Northwest.

are folded and faulted and have a total thickness of several thousand feet. They dip steeply east for the most part. The only igneous rock noted is a dike of granite porphyry, which is 50 feet thick and strikes northwest across the crest of the range at the head of Swartz Canyon, three miles north of the pass.

Rich silver ores were found in the north side of Patterson Pass about 1869. Soon thereafter more than 200 claims were staked, including a few in Swartz Canyon, and a mill was built. About this time or later showings of mineral were also found at and near Cave Spring, on the west side of Cave Valley, six miles northwest of the pass.

The deposits of the district consisted chiefly of small replacement veins of well-crystallized quartz and calcite, mostly in the limestone, accompanied by minerals containing lead, antimony, copper, and iron in moderate quantity. A few thin films of argentiferous lead carbonate and more numerous small pockets of argentiferous copper carbonates were of most interest, but they were shallow and soon exhausted, and the district was abandoned with no record of the early-day production.

In 1913 some work was done on the Robertson property, near the summit of the range on its west side three miles north of the pass. There the showing consisted mainly of crushed and iron-stained shale coated with copper carbonate. At the Swartz property, on the summit of the range at Swartz Canyon, which was also worked at that time, films of sphalerite and pyrite, mostly on joint planes, and a little molybdenite occur in shale that is highly metamorphosed and resembles greenstone.

In 1920 and 1921 the Lake Valley Mining Co. shipped some siliceous silver ore and began building a 50 - ton cyanide plant, in which in 1922–1925 it produced some silver bullion.

In 1920–1930 some work was done on the Cave group, at Cave Spring, and on the Streator group, three miles northwest of the spring. These two properties are described in some detail in the following pages.

DETAILED DESCRIPTIONS

CAVE GROUP

The Cave group of claims, owned by the Great Western Mining & Development Co., is in Cave Valley just north of Cave Spring. It is in the lower west foothill slope of the Shell Creek Range at an average elevation of about 6,700 feet. It lies for the most part on a broad ridge with rolling surface, which declines gently westward into the valley. A portion of it is shown in Figure 1.

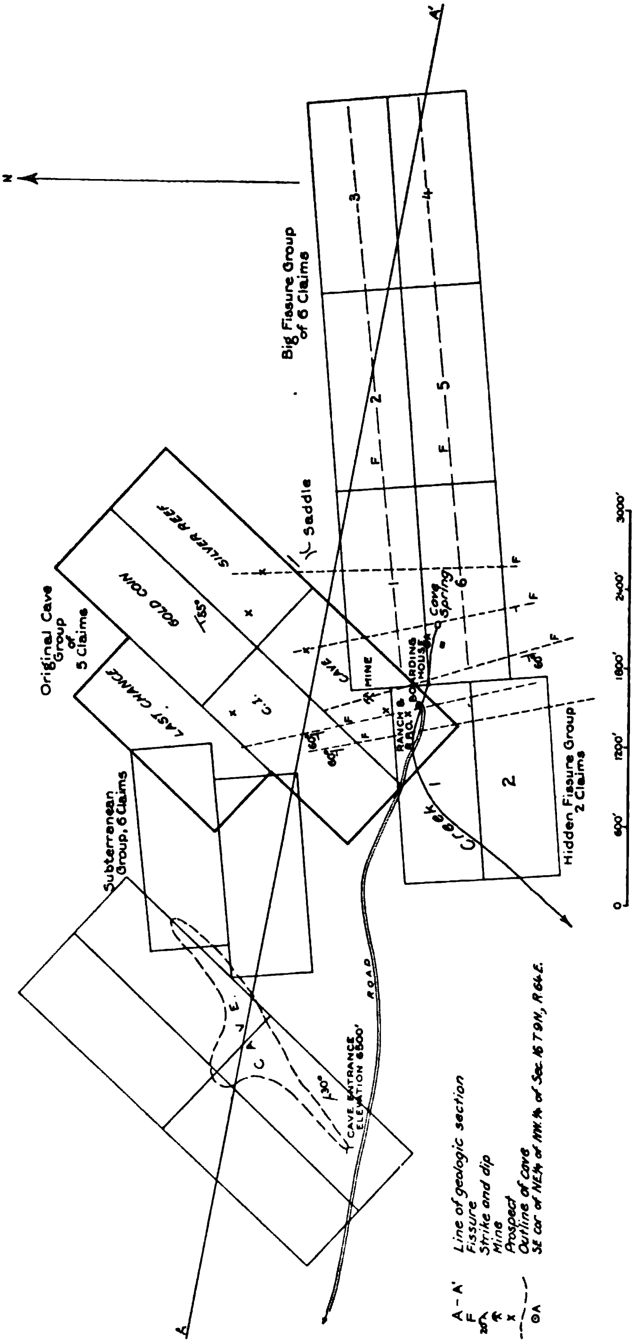
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Fig. 2. Sketch Map of Cave Valley Group of Claims.

History and Production

The Cave group comprises 21 claims, the nucleus and most important part of which is the original group of five claims, inclosed by the heavy border line in Figure 2. These five claims were located in 1921 by John C. Clark and J. C. Riordon, although previously different persons had tried unsuccessfully to work them from time to time.

In 1925 the Ely-Pioche Amalgamated Lead-Silver Mines Co. did some work on them, and in 1926 they were acquired by the Great Western Mining & Development Co., which has since been developing them intermittently on a small scale and has added 16 claims to the original group. According to Mr. Clark, some good ore was mined and shipped during the period of Clark-Riordon and Ely-Pioche ownership. A lot of oxidized lead ore derived from development work was shipped by the Ely-Pioche Co. in 1925.[1]

No further production has been reported except a few test shipments of ore, about five tons each, and a fair quantity of low-grade ore that remains on the dump at the mine.

The workings extend to a maximum depth of 120 feet, as shown in Figure 3. The mine is equipped with a 50-horsepower 8-ton Alamo engine, air compressor, and buildings to accommodate a crew of 16 men. The camp is supplied with excellent water from Cave Spring, which issues in a strong stream from a fissure at the foot of a limestone cliff 30 feet high at the upper edge of the camp.

Geology

The country rocks in Cave Valley are chiefly Cambrian quartzite, limestone, and shale, similar to those at Patterson, and are believed to be a part of the same series. Their relations and attitude are indicated in the section, Figure 4. In general they dip southeastward, or diagonally into the Shell Creek Range, at angles of 20° to 40°. This attitude is similar to that of the rocks at Swartz Canyon and suggests that the Shell Creek Range in this latitude is essentially monoclinal, with easterly dip. The apparent great thickness of the rocks may involve considerable duplication, as they have been much crushed and faulted. Several fault fissures occur near the middle part of the section, as indicated in Figure 4.

Nearly all the fissures trend north and dip steeply to the west, away from the range. On the Big Fissure group the two cross fissures stand about vertical. The south one makes the better mineral showing.

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[1] U. S. Bur. Mines. Mineral Resources, part 1, p. 685, 1925.

The limestones are mostly bluish-gray and blue, more or less crystalline, and medium to thick bedded. The shales occur chiefly as dark intercalated thin beds.

Near the middle part of the section there is a bed of micaceous shale about 100 feet thick. (See Figure 4.) It is lead-gray or iron-gray, dense, closely but dimly banded, more or less finely pyritic, and on weathered joint planes is banded by yellowish-brown limonite streaks one-tenth of an inch or more wide. Locally, especially in the southern part of the Cave Valley mine, it has a pronounced laminated structure. The microscope shows it to be composed of very fine grained quartz, sericite, and secondary calcite, with considerable disseminated pyrite and detrital garnet. It seems to be peculiarly susceptible to mineralization, as the veins of the Cave Valley mine and other prospects occur in it.

The chief ground for referring the rocks to the Cambrian system consists of fossil remains which were found in the present work near the Cave Valley mine and the middle part of the section, in the limestone above the quartzite, and which Mr. Edwin Kirk, paleontologist, of the United States Geological Survey, has determined to be algæ of Cambrian age. The stratigraphic relation of the fossil-bearing limestone seems to be the same as that existing near Patterson, where F. B. Weeks collected Cambrian fossils in limestone that overlies the quartzite.[1]

The deposits consist of replacement bodies along fissures in the limestone and quartzite. The replacement veins along fissures are shown in Figures 2 and 4. The bodies that have replaced certain beds of limestone are as much as two feet in thickness and are regarded as favorable features. They also are mostly associated with fissures, but some of them occur independently, as shown in open pits north of the mine.

Cave Valley Mine

The principal replacement vein is that of the Cave Valley mine, which is opened to a depth of 120 feet and has been followed by 500 feet of drifts, as shown in Figure 3. It strikes north-northwest and dips 80° WSW. in the gray micaceous shale, which dips 45° SE.

Ore is said to have been followed from the outcrop nearly all the way down the shaft, and good ore was mined from short drifts on the 40-foot level. Most of the ore produced, however, came from the south drift and stopes on the 120-foot level.

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[1] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, p. 40, 1903.

The vein seems to be continuous throughout on the 120-foot level, and ore several inches thick is exposed at each end of the drift, particularly the south end; but its thickness on the whole is irregular, ranging from an inch to about five feet. The vein consists of extensive lenses, which in places contain only barren fault gouge or finely crushed rock. In some places the ore and gangue are irregularly banded and streaked.

The ore is siliceous lead-silver-copper with a trace of gold. The gangue is mainly silicified limestone. One test shipment of 4½ tons made by the present owners is reported to have been valued at $85 a ton and another of 5¼ tons at $94 a ton, but the small shipments over a period of several years imply that the quantity of high-grade ore in any continuous body is not great. There is a small amount of ore of milling grade.

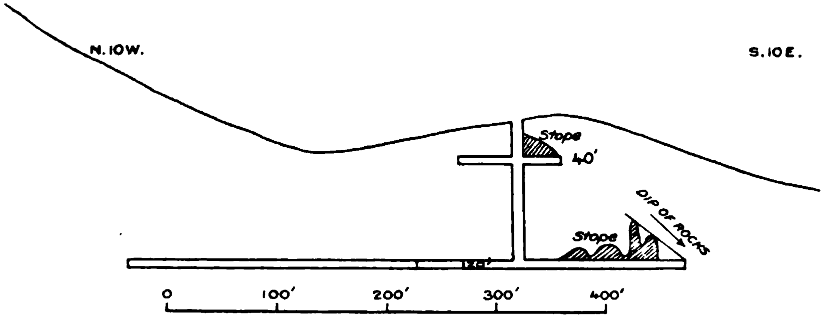

Fig. 3. Longitudinal Section of Cave Valley Mine. Looking East on Hanging Wall Side of Vein.

In places the ore is stained green with malachite or brownish with limonite and lead carbonate, and some of it contains spots an inch or less in diameter of a dull black substance, which may be analogous to "copper pitch ore" in occurrence but seems to carry most of the silver and lead of the ore. Examinations made by M. N. Short, of the United States Geological Survey, indicate that this material is mainly an undetermined oxidized mineral or aggregate of minerals containing arsenic, lead, and a little copper. It is nonmetallic and translucent and gives a light-brown powder when scratched. In polarized reflected light it is isotropic, which probably indicates that it is amorphous. It contains also microscopic remnants of a silvery white metallic mineral which proves to be pearcite, a sulphide of silver and arsenic ($9Ag_2S.As_2S_3$), and has been almost completely replaced by the black mineral. The

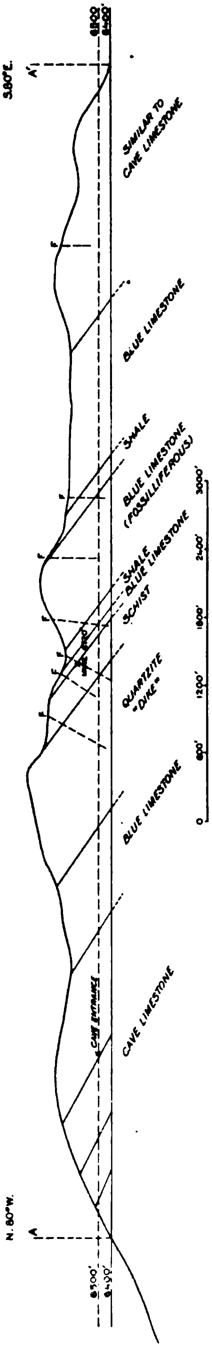

Fig. 4. Diagrammatic Geologic Section at Cave Valley.

pearcite, however, is regarded as primary and the chief source of the silver content of the ore. The trace of gold contained in the ore is probably associated with the pearcite and its oxidation products. Silver is probably present also as horn silver or cerargyrite, or in some other oxidized mineral derived from pearcite and perhaps contained in the lead carbonate.

A thin section from the face of the north drift on the 120-foot level shows that the ore there has essentially a gangue of dimly banded vein quartz. The quartz occurs mostly in elongated forms with very irregular or ragged terminations and borders and exhibits in places a gratelike structure. Other constituents of the vein include bunches of sericite, seemingly derived from argillaceous material of the replaced rock, and considerable secondary calcite, which occurs (a) interstitially in the quartz, (b) as veinlets and seams, and (c) as minute, slightly greenish rhombs scattered throughout the section. Pyrite is present in small amount, as is also the dull black mineral with pearcite inclusions, which occurs in irregular spots and in seams or veinlets and is associated in places with calcite. Here and there, especially on joint planes and fractures, the ore is coated or stained with a yellowish-green powdery finely crystalline mineral. This was formerly thought to be uranium oxide or carnotite, but it has been positively indentified in the present work as psittacinite, a hydrous lead-copper vanadate ($2PbO.2CuO.V_2O_5.2H_2O$) containing much vanadium, lead, and copper and a trace of zinc. As the presence of uranium and radium had been reported, however, seven representative ore specimens were collected from well-distributed parts of the Cave Valley deposits and were tested for these elements by the radiograph method. Six of the specimens came from the Cave Valley group property and included one from the clay deposit in the cave. The seventh was from the Streator group of claims. Photographic plates were exposed to the specimens for periods of one to ten days, without giving any trace of radioactivity. Chemical tests of the ore also failed to show any trace of uranium oxide or any radium-bearing mineral.

Clay in Cave Valley Cave

The cave from which the valley takes its name is covered by the Subterranean claim group, shown at the left in Figure 2. Although it lacks the stalactites and stalagmites that are features of many limestone caverns, this cave has long been visited as a point of interest by people of the surrounding region. It is very accessible, the entrance being nearly on a level with the road at the foot of the limestone ridge. The cave is said to extend northeastward beneath the ridge for 2,300 feet and to have a maximum width of about 600 feet. Its floor is nearly horizontal, and its ceiling in general stands six feet or more above the floor.

A possible economic feature of the cave is a clay deposit that forms the floor for a distance of at least 1,500 feet from the portal and perhaps for the full length. This deposit has a maximum thickness of 40 feet or more. The clay has recently been explored by the present owners to a depth of ten feet without reaching bottom, and a prospect shaft is said to have been sunk by Mr. Robinson to a depth of 40 feet without reaching bottom. Mr. Robinson reported that he found silver in the clay in this shaft but not enough to encourage further prospecting. The clay so far as seen by the present writer is stained a decided red by iron oxide, but it is said to become yellowish in the deeper part of the cave.

The clay is slightly streaked or laminated. It is very homogeneous, free from grit of any kind, and smooth or talcose to the feel. A partial analysis made for the owners by Crismon & Nichols indicated 27.8 per cent aluminum oxide, 0.4 ounces silver to the ton, small quantities of iron, phosphorus, lime, magnesium, and silica, and traces of gold, copper, arsenic, antimony, and vanadium. It also showed 0.251 per cent of uranium oxide, but a specimen of the clay collected by the writer from a pit 8 feet deep and 600 feet in from the portal of the cave showed no trace of radioactivity in the radiograph test.

The deposit is estimated to contain about 200,000 cubic yards of clay, but the red color of its upper part and the yellow color of the remainder imply that the iron content is too high to adapt the clay for high-grade uses, and costs of transportation to centers of consumption afford no hope for its development at present.

STREATOR GROUP

The Streator group, which is also owned by the Great Western Mining & Development Co., is situated in the foothills about three miles northwest of Cave Valley, at an elevation of about 7,000 feet, and is easy of access. The hills here support a moderate growth of cedar, juniper, and pinon.

The property comprises a group of five claims known as the Consolidated group. (See Figure 5.) It is reported to have produced some high-grade shipping ore at a relatively early day. About 90 tons of mill ore lay on the mine dump at the time of visit. Considerable work is said to have been done in 1929, and some in shallow openings was done as late as June, 1930.

The property is developed at several points by shallow openings, the largest of which, known as the Streator mine or shaft, is on the Consolidated No. 1 claim and has a depth of 60 feet.

The country rocks are blue limestone, quartzite, and schist and are evidently continuations of those at Cave Valley, though the quartzite here seems to be lighter in color. They dip about 40° SE., and here, as at Cave Valley and Patterson, the mineral deposits occur in the limestone and schist above the quartzite.

The ores contain lead, silver, and copper and are very similar to those at Cave Valley in general occurrence, appearance, and mineral composition, but the psittacinite stains are here more conspicuous, and some of them have a pronounced canary-yellow color. The ores occur mostly as replacement deposits in silicified limestone in a gangue of quartz, barite, and altered rock. The chief ore mineral is argentiferous galena, but spots of the dull-black mineral with pearcite inclusions as much as three-tenths of an inch in diameter are also present. Some of the ore consists chiefly of silicified limestone, stained by yellowish-brown iron oxide and by lead and copper carbonates. It is crudely ribbed or banded with stringers of replacement quartz as much as two-tenths of an inch wide, which are associated in places with smaller

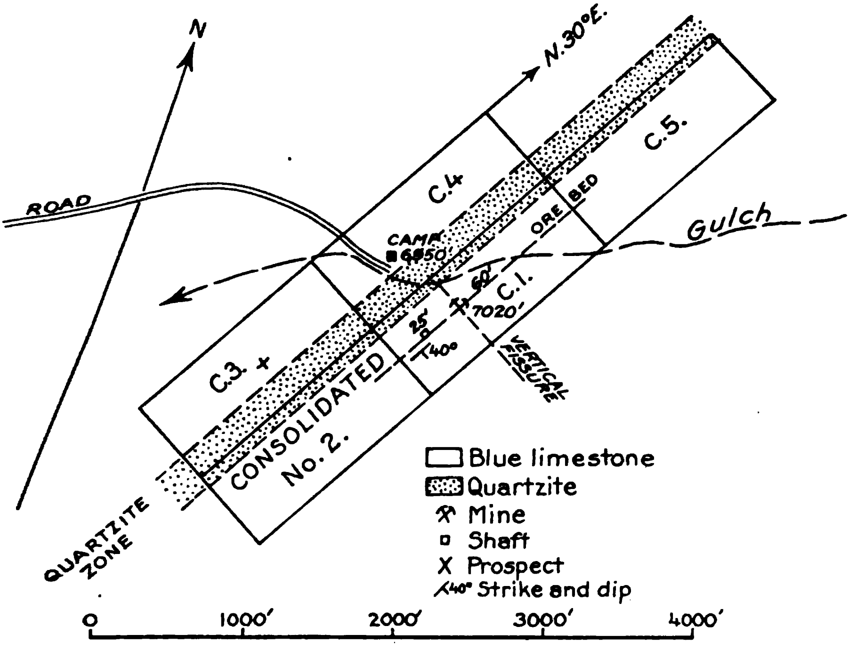

Fig. 5. Sketch Map of Streator Claims.

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